

• Giants of Palomar •

Front Cover

The dome of the 200-inch Hale Telescope on Palomar Mountain.

The Russell Porter pastel drawing on the front cover shows the dome of the 200-inch Hale Telescope, the principal instrument at the Palomar Observatory of the California Institute of Technology. Development of the observatory began in 1928 when the California Institute of Technology received a grant of six million dollars from the International Education Board of the Rockefeller Foundation. On June 3, 1948, the completed telescope was dedicated to the memory of George Ellery Hale, whose leadership and vision were responsible for the creation of this unique tool for astronomical research.

The dome is 135 feet high and 137 feet in diameter, rivaling in size the Roman Pantheon. The dome is in two sections; the solid lower portion is immovable, whereas the upper section can be rotated to permit the telescope within to scan any portion of the sky through open shutters. The base section houses photographic darkrooms, telescope-control computers, library, lounge, storerooms, air-conditioning equipment, photographic plate storage vault, motor generators, massive switchboards, elevators, and an oil-pumping system that supplies the major bearings of the telescope. On the uppermost floor of the solid section stands the telescope. Adjacent to it is a glassed-in observation gallery where visitors can view the instrument during daylight hours.

The movable upper section of the dome weighs 1000 tons, yet it turns so smoothly on carefully ground tracks that no vibration is created that might interfere with the perfect operation of the telescope. The two shutters, shown open in this drawing, weigh 125 tons each. They roll together at the end of each night's work to seal the interior against the heat of the day and inclement weather. Incorporated in the dome are thick insulation and carefully planned ventilation to maintain the interior as close to nighttime temperature as possible so that the delicate instrument it houses will not be adversely affected by temperature changes. Only for very special observations are the shutters opened during the daytime as shown in this artist's conception of the scene.

Giants of Palomar

Drawings by

Dr. R.W. Porter

1871-1949

Text revised in 1983 by the staff
of Palomar Observatory.

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Introduction

Instruments such as the 200-inch reflector and 48-inch Schmidt telescopes are actually huge cameras rather than instruments through which astronomers look at the stars. By focusing the light of celestial objects onto sensitive photographic plates, photoelectric detectors, and solid-state devices, these telescopes can record objects thousands of times fainter than can be perceived by direct observation. Furthermore, visual observations are unreliable, subjective impressions in the mind of a single individual and are unavailable for objective study by anyone else. Photographs and images recorded on magnetic tape provide permanent records that may be studied in detail by generations of astronomers.

There are other types of permanent records of immense value that can be made with many telescopes. For example, light gathered by the 200-inch mirror can be directed through an instrument called a spectrograph to disperse the light into a rainbow of colors called a spectrum, which may then be detected and recorded. The spectra of most astronomical objects are crossed by bright or dark lines of various intensities that are characteristic of the chemical elements present. Careful study of the positions and relative intensities of these lines reveals not only what elements are present, but their relative abundances, the temperature of the object, its velocity toward or away from the earth, its rate of rotation, the presence of magnetic fields, even the presence of faint traces of gas scattered thinly throughout the vast intervening space through which the light passed before reaching the earth.

Much can be learned from studies of the brightnesses and relative colors of stars. Once accomplished exclusively by photographic methods, such measurements are now made more quickly and precisely by highly sensitive photoelectric cells in combination with electronic amplifiers. Such information can be fed through computer systems that greatly reduce the labor of the astronomer, yielding results in seconds or minutes that previously required weeks or months to derive. The telescopes on Palomar use every new and improved technique that will help to increase man's knowledge of the universe around him. First, however, there must be powerful instruments with which to work. The following pages illustrate and describe some of the design and mechanical features of the 200-inch reflector and the 48-inch Schmidt telescope so that the layman will have an understanding of the tools with which astronomers work.

Astronomers from all over the world visit Palomar for a few days, weeks, or months at a time to use the telescopes. They then return to their home institutions to make detailed analyses of the material they have gathered at Palomar and prepare the results for publication in scientific journals. Meanwhile, other astronomers take their turn at the instruments.

The offices and laboratories of staff astronomers are located at the California Institute of Technology in Pasadena (near Los Angeles) where as faculty members they also conduct classes in astronomy and astrophysics for undergraduate and graduate classes at Caltech. Both observational and theoretical instruction is offered in a broad range of advanced studies and research.

Foreword to First Edition, 1947

By Dr. Max Mason
Chairman of the Observatory Council

George Ellery Hale, that great astronomer and statesman of science, conceived the project of building a telescope of two hundred-inch aperture. Funds for the construction were given to the California Institute of Technology by the Rockefeller Boards.

The staff of the Mount Wilson Observatory of the Carnegie Institution of Washington joined with the scientists and engineers of the California Institute of Technology in directing the long task of scientific study and precise engineering.

The great telescope is a light-gathering instrument—a fast telescopic camera. It will be used photographically, not visually, to study faint and distant nebulae, those universes of suns, and to analyze into high detail the nature of the light received from stars and planets, to penetrate farther into the distant reaches of space, photographing over hours of exposure time the remote members of the cosmos.

First, then, more knowledge of the make-up of the cosmos. But there is another phase of modern astronomy. All science today is really one, its field the study of the electrical constitution and the behavior of the elements. We study this in terrestrial laboratories. But in the stars, and in interstellar space, matter exists under conditions which we cannot reproduce on earth. We cannot reproduce the enormous temperatures and pressures within the suns. Nor can we pump out the gas of a vacuum tube to have matter in as rarefied and attenuated a form as exists in interstellar space. The astrophysicist analyzes the light received from the suns and the effect on it of the attenuated gas in space and so uses the whole of the cosmos as a laboratory to learn of nature's laws.

Man wants to know and nothing will stop him. We grope dimly through our ignorance, driven by an insatiable curiosity inherited from our simian ancestors. We feel that we are a part of an all-enriching unity. We have learned that all matter is alive, sending energy, the source of life, back and forth through space, and that we, organic life in evolution, are a part of the great orderly universe. Our knowledge is in its infancy, but we press rapidly forward, learning of the make-up of the cosmos, the evolution of the stars as they are born, mature and age, the life history of a whole universe of suns, and the laws of behavior of the very matter which makes the bodies which our minds and spirits inhabit. We seek nothing less than clues to the great mystery of existence, and knowledge to gain conscious control of man's evolution.



The Artist

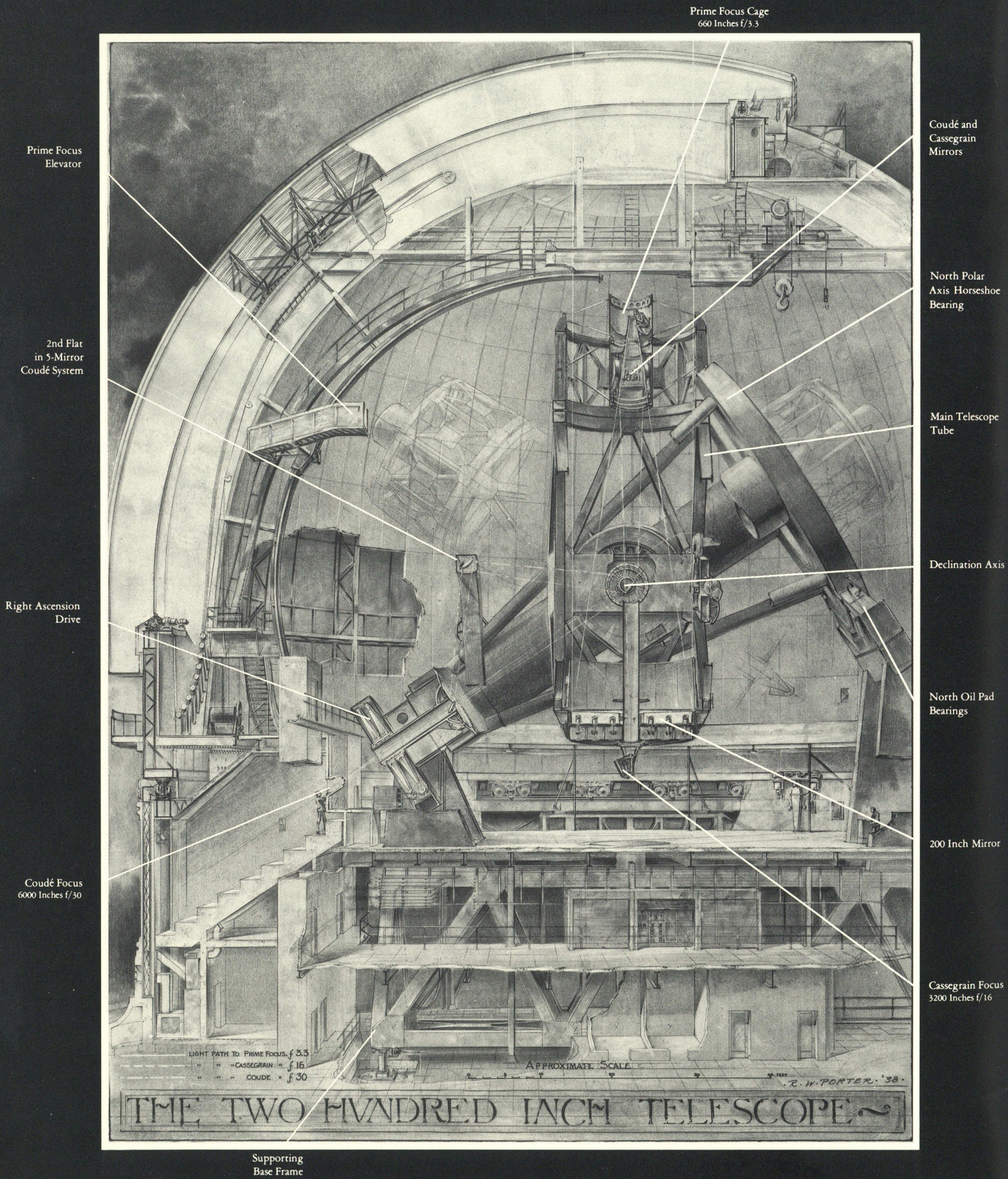
Dr. Russell W. Porter, well known to amateur telescope makers the world over, made this unique collection of drawings over a period of 12 years using his amazing ability to faithfully portray mechanical objects in perspective with nothing to work from but mechanical blueprints. With pencil and paper he was able to "cut away" sections of the telescope to show the inside details, something that cannot be done with any camera. His artistic and mechanical abilities have combined to produce a set of drawings that have proved of indispensable value not only to the layman but even to those who already are familiar with the instruments. Dr. Porter is shown at the left working on one of the drawings in this book.

Maxfield Parrish, celebrated fellow artist, had this to say of the Porter drawings: "If these drawings had been made from the telescope and its machinery after it had been erected they would have been of exceptional excellence, giving an uncanny sense of reality, with shadows accurately cast and well nigh perfect perspective; but to think that any artist had his pictorial imagination in such working order as to construct these pictures with no other material data than blue prints of plans and elevation of the various intricate forms—is simply beyond belief.

"These drawings should be in a government museum of standards, in a glass case, along with the platinum pound weight, yard stick, etc., to show the world and what comes after just what a mechanical drawing should be.

"Not only that, but the rendering is a work of art, exact and lifelike, and done with a delightful freedom of technique.

"I doubt if there are drawings anywhere which can in any way compare with these for perfection in showing what a stupendous piece of machinery is going to look like when finished. . . . Their creation should be world news."



Key Drawing

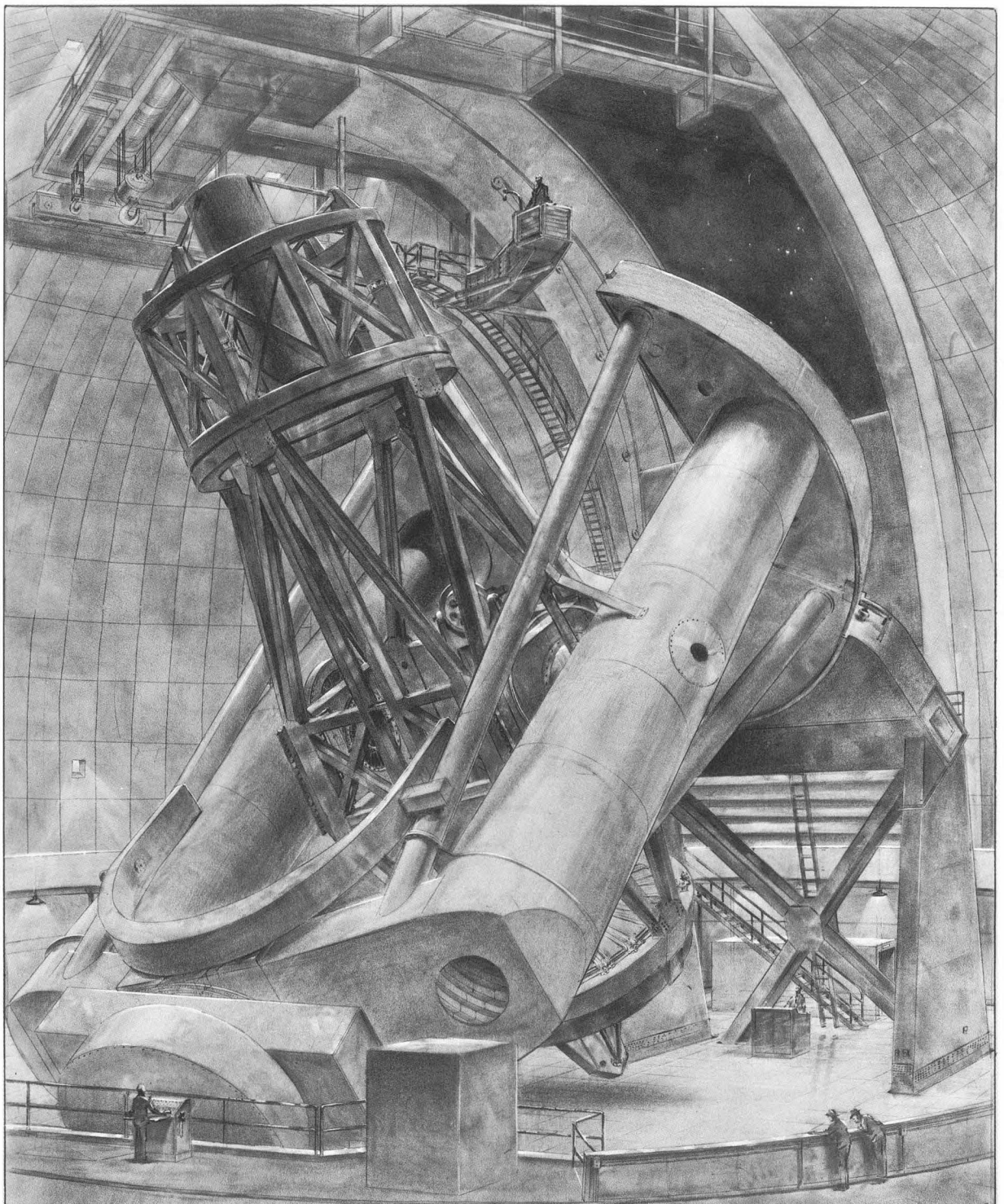
This is a meridian cross-sectional drawing of the 200-inch Hale Telescope and dome with marginal identification of major features illustrated and described in the following pages.

The vertical structure near the center of the picture is the main telescope "tube" that carries the 200-inch-diameter mirror at its bottom end. The astronomer, when he or she so desires, can work at the focal point of the mirror in the capsule suspended in the center of the tube at the top end, actually riding in the telescope. The main tube, weighing 150 tons, is supported on ball-bearing trunnions anchored in the large yoke, which consists of two 10-foot-diameter inclined tubular girders tied together at the south end (left) by a cross member supported on a pivot bearing and at the north end by a giant horseshoe bearing. The tube and supporting yoke, which are the moving parts of the telescope, weigh a total of 530 tons.

Light from a celestial object is concentrated by the 200-inch concave mirror into an image at the "prime focus" at the upper end of the tube. Longer focal lengths—and hence large images—can be provided by inserting one or the other of two convex mirrors just ahead of the prime focus. The first of these, known as the Cassegrain secondary mirror, reflects the light back down the tube through a hole in the center of the main mirror to a focus just below the bottom of the tube. If a still larger image is desired, the second convex mirror is substituted. With the aid of a diagonal flat mirror it sends the light down through the south polar-axis to a constant-temperature room, seen at the lower left, in the stationary portion of the dome. White lines in the drawing show the paths followed by light rays in these different mirror combinations.

Encircling the south end of the polar axis are two huge gears, one of which is used to "slew" the telescope east or west while aiming it at the desired object in the sky. The other drives the telescope, after it has been set on an object, at a rate of one revolution in 24 hours to compensate for the rotation of the earth.

Ghost inserts of the upper end of the tube show it pointing at the north celestial pole and at a point just south of the celestial equator. The first demonstrates the reason for a horseshoe bearing; it permits the tube to reach the pole without interference. The second ghost drawing shows how the astronomer can reach the prime-focus capsule from the special elevator shown midway up the curved track just inside the dome shutters. By raising and lowering the elevator and rotating the dome, he or she can reach a point where it is possible to step into the capsule regardless of where the telescope is pointing. On the ground floor are offices, laboratories, and utilities.



THE • TWO • HUNDRED • INCH •
TELESCOPE • LOOKING • NORTHWEST

The 200-Inch Hale Telescope, Looking Northwest

*A general view of the instrument
as it appears at the start of a
night's work before the lights are
extinguished.*

Through the open shutters of the dome the sky is nearly dark and stars are shining. The astronomer in the drawing is riding the special elevator to the prime-focus capsule where he will work throughout the night using photographic plates, a spectrograph, or a photoelectric-photometer.

Until the astronomer is safely in the prime-focus capsule with all of his equipment and the elevator has been sent back down, the mirror covers, visible just below the right-hand tubular girder, will remain closed to protect the mirror from damage should any object accidentally be dropped from above.

Below the telescope at the foot of the north pier is the control desk where an assistant once controlled the mechanical operation of the instrument to aim the telescope at the objects that the astronomer wishes to study, performs the host of duties involved in the efficient operation of the telescope, and helps to keep records of the night's work. More recently, these functions are performed in a special control room constructed on the observing floor.

At the lower left is a console containing controls for adjusting the balance of the telescope and for inserting the secondary mirrors that change the focal length of the instrument.

The cube in the foreground is the top of the passenger elevator shaft that carries astronomers from the offices and darkrooms on the ground floor to the observing floor.

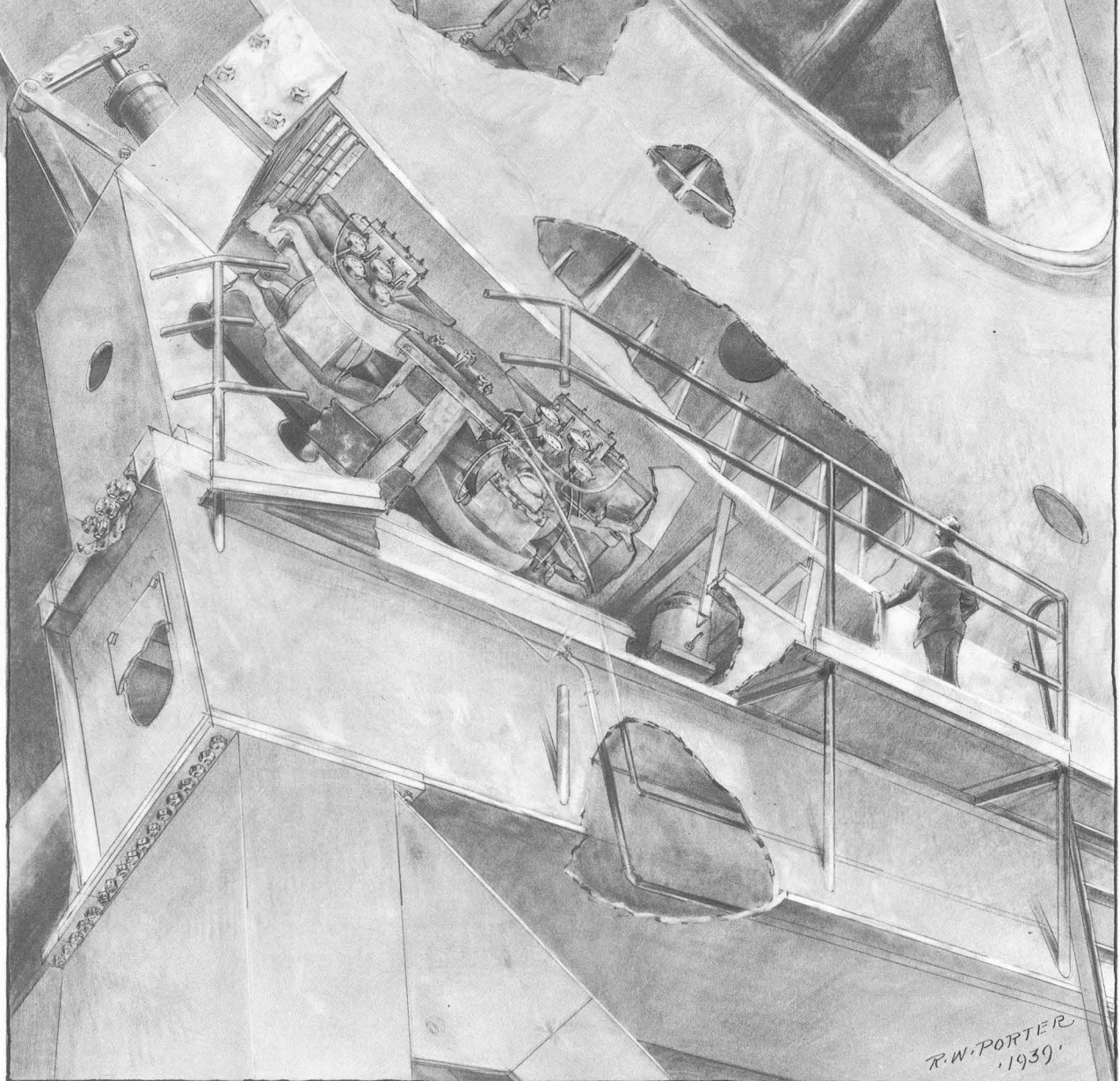
When the telescope tube is being pointed at an astronomical object, the tube swings north or south on trunnions anchored in the sloping tubular girders of the main yoke. The yoke rotates east or west on the large horseshoe bearing at the north end and a pivot bearing at the south end of the yoke. The dome automatically turns until the open slot is over the end of the tube, permitting the telescope to view the desired part of the sky.

When the astronomer is ready to start work, all lights are extinguished and work begins. Measurements of faint astronomical objects may last anywhere from a few minutes to several hours. These days, using remotely operated instruments and very sensitive television systems attached to the telescope, the astronomers and the telescope operate work in the control room on the observing floor.

Every dark hour of every clear night is utilized with this telescope to probe the depths of space for answers to many puzzling questions relating to the nature and extent of the universe.

• NORTH • POLAR • AXIS • BEARING •
HORSE SHOE • & •
• OIL • PADS •

SHOWING DVST SHIELD
REMOVED



• TWO • HUNDRED • INCH • TELESCOPE •

North Polar-Axis Bearing

This horseshoe-shaped bearing at the north end of the yoke glides on a film of oil giving almost complete freedom from friction despite the tremendous load.

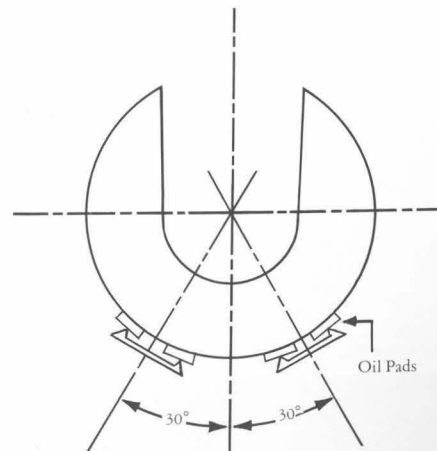
As described on page 17 the telescope must swing slowly and smoothly from east to west to compensate for the rotation of the earth on its axis. To do this the telescope must be equipped with very efficient bearings that can carry the great weight of the instrument with minimum friction. This is relatively easy to accomplish for rapidly moving bearings because their speed carries a film of oil between the moving surfaces, but when they turn only one revolution in 24 hours, the film of oil has more than ample time to drain away, permitting the bearing surfaces to touch, generating intolerable friction.

Since the telescope moves too slowly to carry the lubricating oil through the bearing, the problem was solved by pumping it through under high pressure. The drawing below shows the bearing at the north end of the yoke, which is in the shape of a thick horseshoe with its broad, outer surface ground to high precision. It rests on four large metal pads machined to fit closely the curve of the horseshoe. In order that these pads will both support and accurately define the position of the north bearing, they are located as shown in the small sketch at the left. Two of these pads with their oil supply lines and pressure gauges can be seen in the drawing.

Oil is pumped through the pads at a pressure of about 300 pounds per square inch, sufficient to lift the horseshoe and its load a few thousandths of an inch. The oil flows outward through this narrow gap in a uniform film, preventing the bearing surfaces from touching at any time while the telescope is in operation. Similar oil pads at the south end of the yoke, described on page 15, perform a comparable function. Between the two the entire 530 tons of moving parts of the telescope are "floated" on films of oil, providing virtually friction-free operation.

As the oil escapes it is caught, filtered, returned to the pumps, and recirculated again and again. Should the oil pressure drop for any reason, a warning signal is sounded throughout the dome. If remedial action is not taken before the oil film decreases to a point where there is a danger that the bearings might touch and cause damage, all driving power to the telescope is automatically shut off.

The motion of the 530-ton instrument on these bearings is so free from friction and the telescope is so precisely balanced that the entire mass is made to follow the stars by a mere 1/12th horsepower motor! If all motive power is disengaged, the telescope can be moved by the steady pressure of one finger!



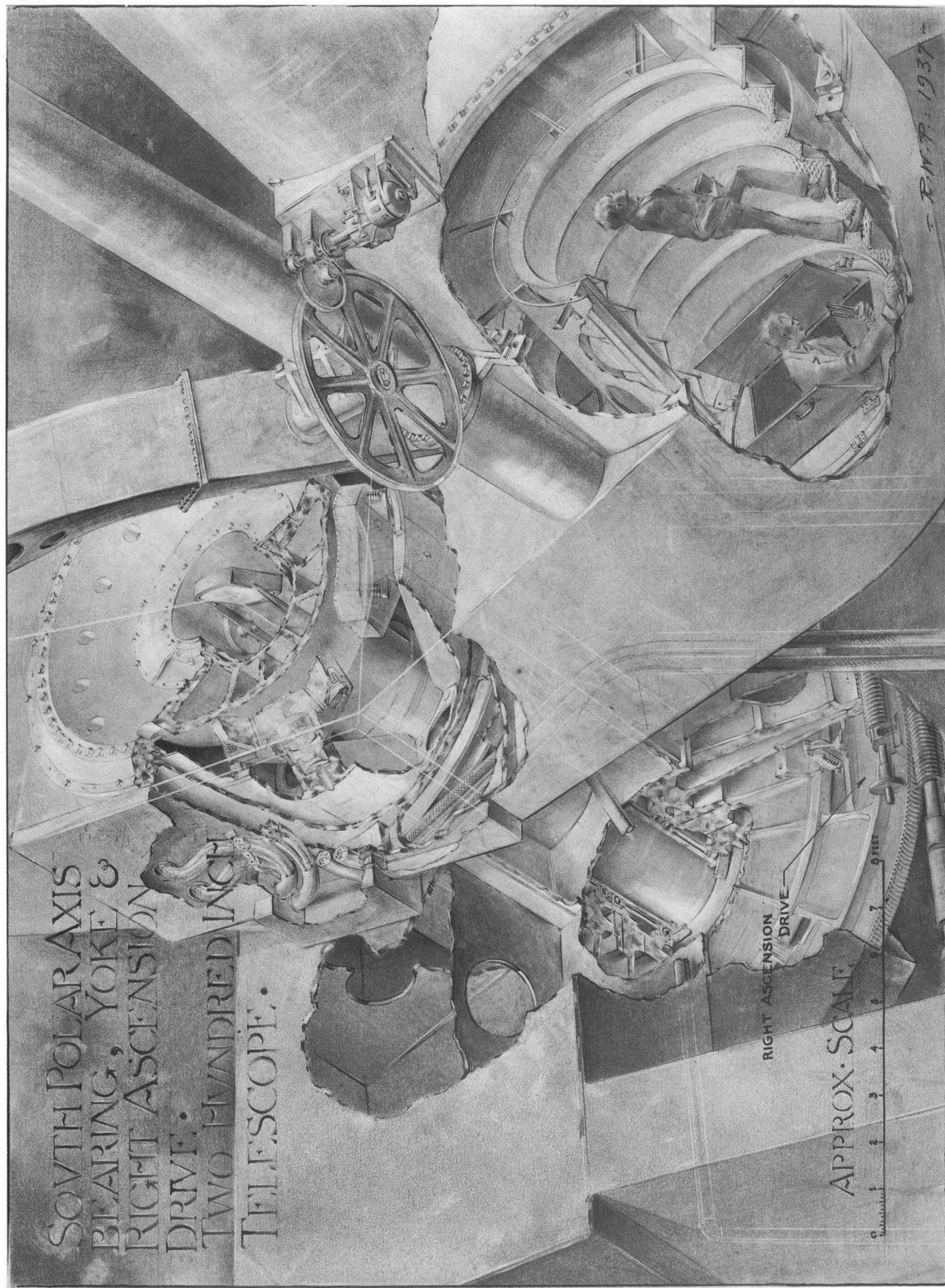
SOUTH POLAR AXIS
BEARING, YOKE &
RIGHT ASCENSION
DRIVE.
TWO HUNDRED INCH
TELESCOPE.

RIGHT ASCENSION
DRIVE

APPROX. SCALE

0 1 2 3 4 5 6 7 8 9 FEET

- R.W.P. 1937 -



South Polar-Axis Bearing, Yoke, and Right Ascension Drive Gears

A general view of the south end of the main yoke of the telescope showing the relationship of several major features illustrated and described in subsequent pages.

The complicated drawing at the left probably demonstrates better than any other the amazing skill of the artist who had nothing from which to work except reams of blueprints showing cross-section and plan views.

This drawing shows the yoke tilted far over to one side. The large member extending across the center of the picture from upper left to lower right is the cross-member at the south end of the main yoke. The lower end of the 10-foot-diameter east arm of the yoke is seen in cutaway section at the lower right with two men ascending the stairway within.

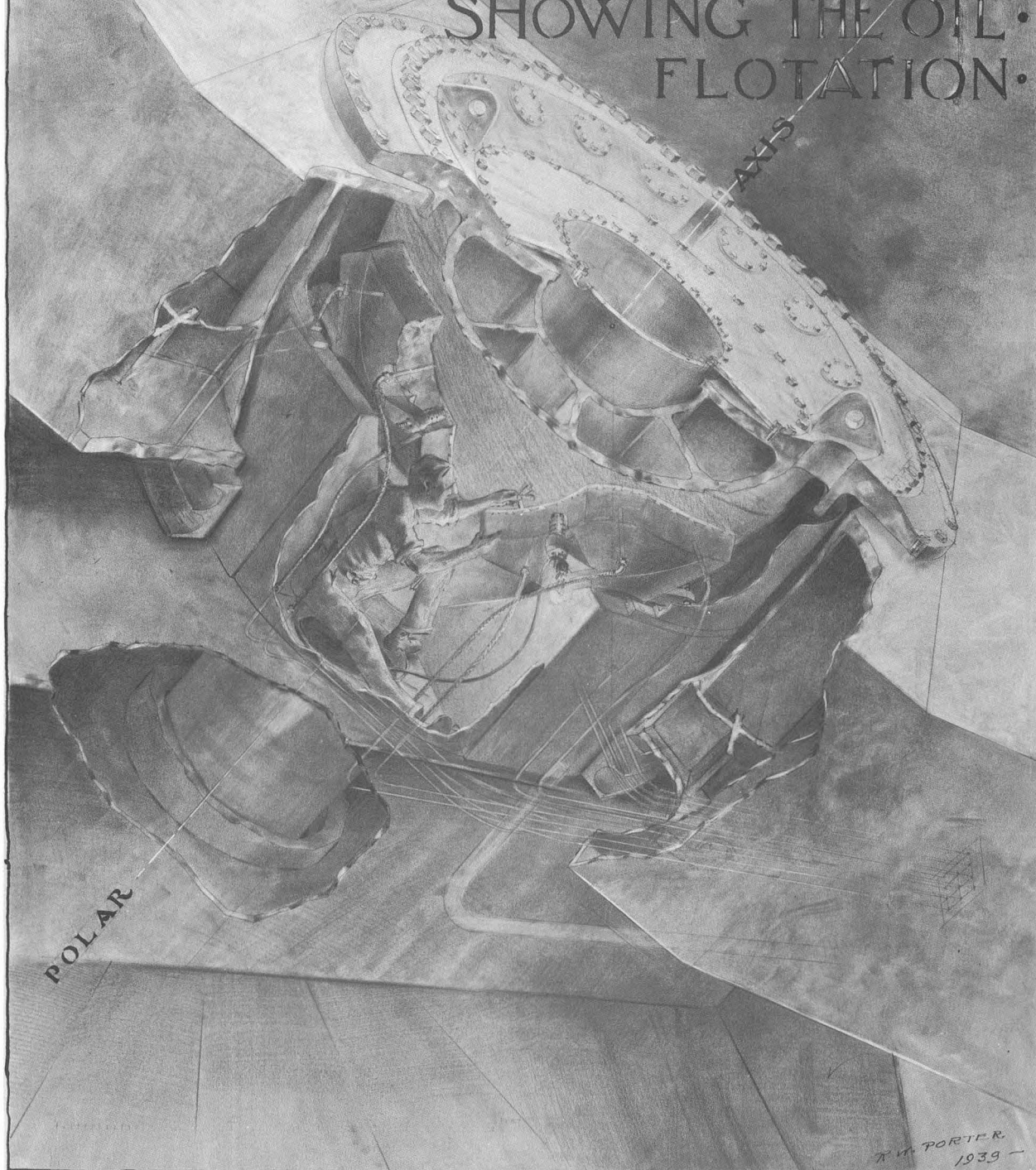
Higher up in this arm, at the declination trunnion, (out of this picture) are located spectrographs and other equipment that are used when the telescope is set up with the Cassegrain combination of mirrors, as described on page 41.

Above the heads of the men, outside the east arm, is a motor and gear train operating a curved beam rising almost vertically out of the picture. This is one leg of the arch that carries an auxiliary flat mirror (see picture on page 6), one of three that are sometimes required in the combination that gives the telescope its longest focal length, known as the coudé arrangement. To the left of the arch can be seen a diagonal flat mirror at the entrance to an inclined hollow shaft. This is the last in the train of five mirrors in the coudé system that directs starlight through the south polar-axis to the spectrograph room in the solid portion of the dome, described in detail on page 43.

Encircling the upper end of the hollow shaft and diagonal mirror can be seen a large metal hemisphere resting on a metal pad that is directly below the mirror. A second pad can be seen to the left of the mirror; a third pad is out of sight behind the hemisphere. These three pads support the weight of the south end of the main yoke, and in combination with the hemisphere, comprise the south polar-axis bearing, described on page 15.

At the lower end of the hollow shaft are two large gears. One of these rapidly swings the telescope east or west while it is being aimed at an object; the other slowly drives the telescope from east to west to compensate for the rotation of the earth. These gears are shown to better advantage on page 16.

SOVTH · POLAR · AXIS · BEARING ·
SHOWING THE OIL ·
FLOTATION ·



· THE · TWO · HUNDRED ·
· INCH · TELESCOPE ·



South Polar-Axis Bearing

A steel hemisphere, three metal supporting pads, and a film of oil make up the essential parts of the bearing at the south end of the telescope yoke.

The man visible near the center of the cutaway drawing at the left is checking the space between one of three large metal pads and a steel hemisphere that rests on those pads. The hemisphere is bolted to the south cross-member of the telescope yoke, and the pads are supported on a rigid foundation. Together they make up the south polar-axis bearing that carries a share of the weight of the telescope, and, in combination with the horseshoe bearing at the north end, allows the instrument to swing east and west.

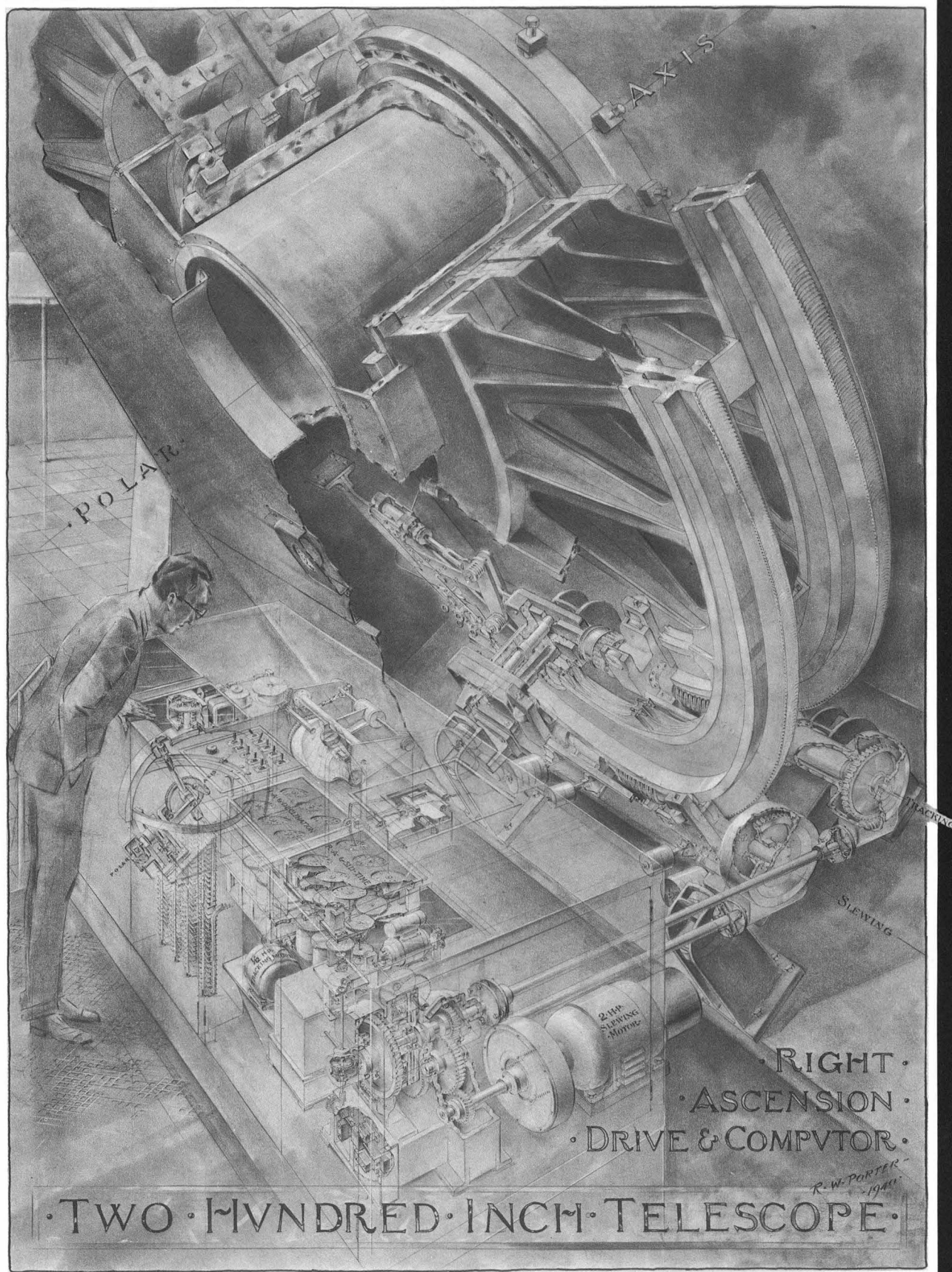
To permit this bearing to work smoothly and free from friction the same principle is applied that is used for the horseshoe bearing; oil is pumped under 300-pound pressure through holes in the three pads into the gap between the pads and the hemisphere. In an effort to escape, the oil lifts the hemisphere away from the pads a few thousandths of an inch, just enough to allow the oil to flow outward in a thin, uniform film. The hemisphere literally floats on this oil film and is free to rotate virtually without friction despite the tremendous load it carries.

The pads are positioned in such a way that they simultaneously support and accurately define the position of the hemispherical bearing, allowing no lateral motion, only rotation.

The man in the picture is making one of the periodic checks of the thickness of the oil film to assure smooth performance. The same safety device is provided at the south bearing that was described in connection with the horseshoe bearing to warn if the oil pressure drops to a point where there is danger that the bearing surfaces will touch.

This system of oil-flotation support for the 530-ton instrument was almost too good; dampers had to be installed to prevent the telescope from responding to movements of an observer in the prime-focus capsule, or gusts of winds that occasionally blow into the dome.

Clearly visible in the drawing is a large hollow shaft extending through the entire south bearing and out of the picture at the lower left. When the telescope is used at its longest focal length, the light beam passes downward through this hollow shaft to spectrographs in the constant-temperature room below. For the details of what lies at the left end of the shaft, and beyond, see pages 17 and 43.



RIGHT ·
ASCENSION ·
DRIVE & COMPUTER ·
R. W. PORTER ·
1940 ·
· TWO · HUNDRED · INCH · TELESCOPE ·

Right Ascension Drive and Computer

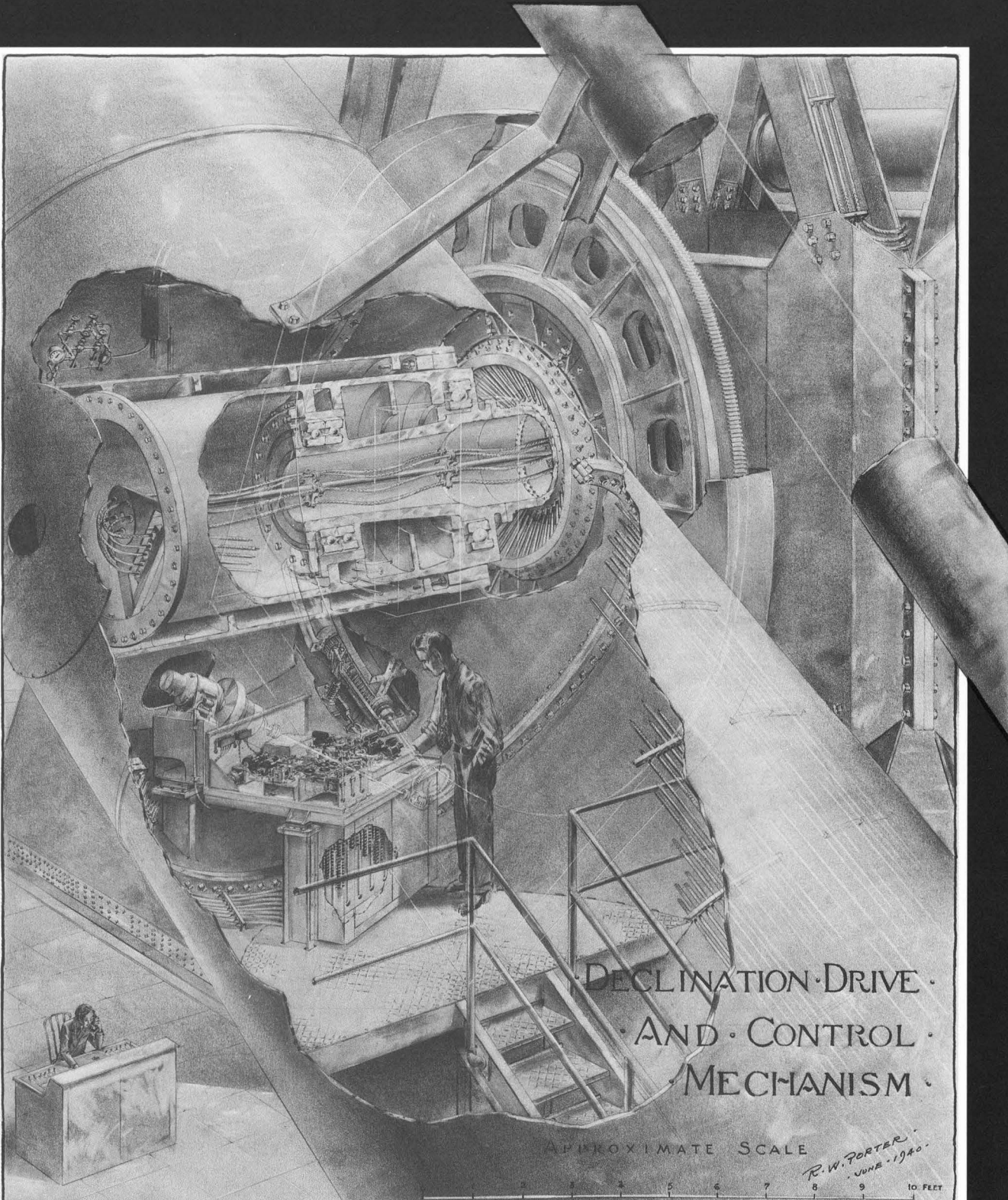
Two large gears are used to move the telescope; one slews it east or west into the required position, the other makes it follow the stars. A computer system simplifies the task of aiming the telescope.

The positions of astronomical objects in the sky are specified in much the same manner as are geographical points on the surface of the earth—by a reference system of imaginary lines. On earth the system consists of imaginary circles of latitude for positions north or south of the equator, and meridians of longitude for positions east or west of a chosen reference meridian. The sky is similarly divided by imaginary reference lines, but they are called declination rather than latitude for north-south positions, and right ascension in place of longitude for east-west position.

Because of the rotation of the earth, the stars and their reference system of positions appear to move westward when viewed from an observatory. Therefore, when determining the direction in which to point the telescope to view a specific astronomical object, it is necessary to know the coordinates of the object, the sidereal (star) time, and the position of the telescope. To accomplish this task, the two rotation axes of the telescope are equipped with extremely precise digital encoders to measure its position at all times. This information and the sidereal time signal from a very accurate electronic clock are used by a high-speed digital computer to bring the telescope to point at the object to be studied. By including other, more subtle effects such as atmospheric refraction and flexure of the telescope structure, it is possible to point the telescope to an accuracy of a few seconds of arc. (One second of arc is the angular size of a 25 cent piece viewed from a distance of 3 miles.) Once the object has been centered in the field of view, the computer then controls the telescope's fine drive motors to follow it across the sky as the earth turns, maintaining the correct position to a few tenths of a second of arc.

The picture at the left shows the south end of the polar axis and two 14-foot gears. One is used to initially slew the telescope into position, the other is connected to the fine drive of the instrument so that it follows the motion of the stars across the sky at a rate exactly compensating for the effect of the earth's rotation. The left-hand of the two large gears automatically clamps to the polar axis when the telescope is to be slewed into position, while the right-hand gear floats free. When the setting is complete and the slow driving rate is to take over, the first gear unclamps and the drive gear clamps to the polar axis. A 2-horsepower motor slews the 530-ton instrument into position, but only 1/12th horsepower is required to drive it as it follows the stars.

Light passes downward through the hollow shaft above the man's head when the telescope is used at its longest focal length. The focal point lies a short distance behind the man, where the entrance slit of a series of spectrographs is located, described, and illustrated on pages 42 and 43.



DECLINATION DRIVE
AND CONTROL
MECHANISM

APPROXIMATE SCALE



200 INCH TELESCOPE

West Declination Trunnion

One of the two bearings about which the main telescope tube tilts north and south within the large yoke.

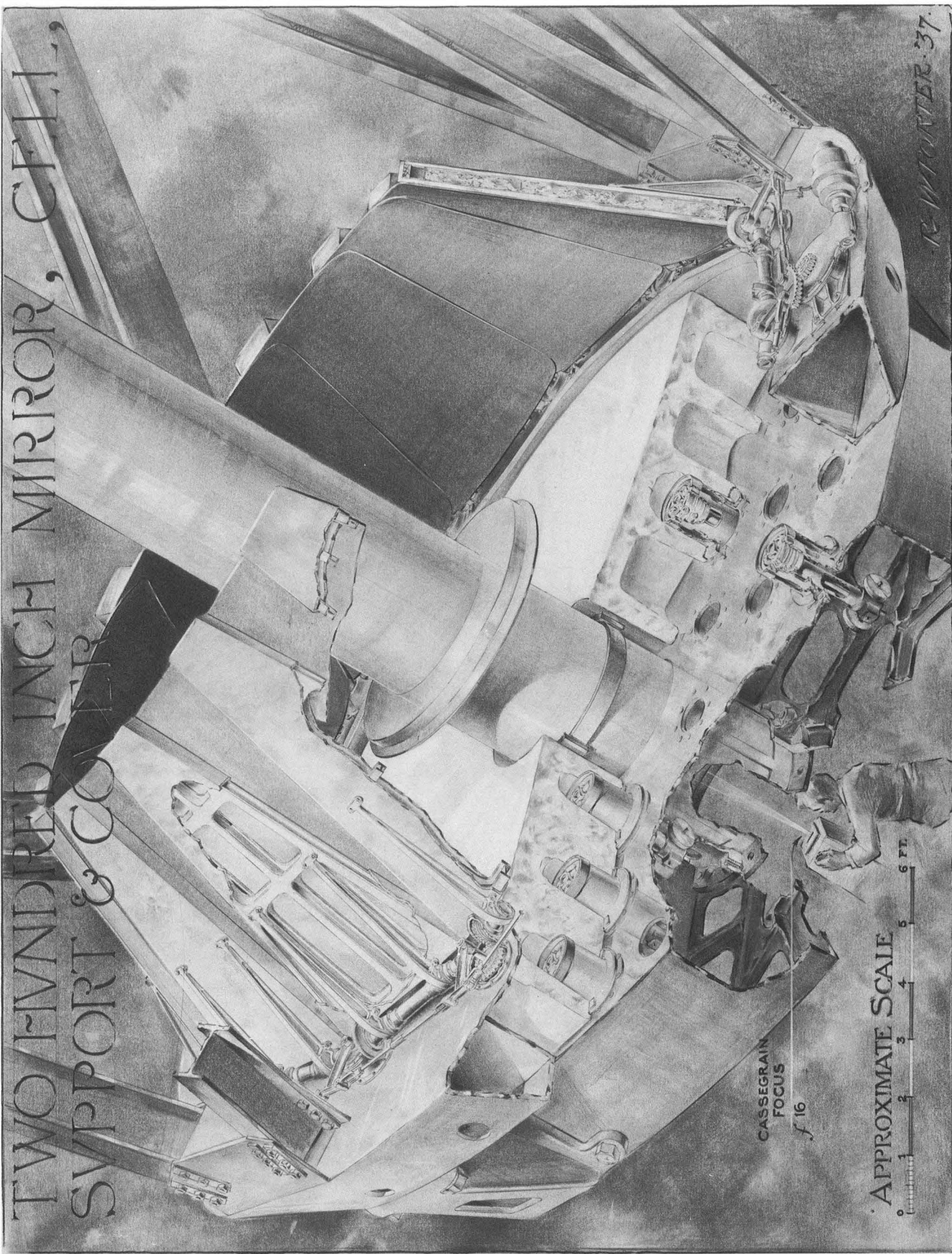
The main telescope tube is supported between the two 10-foot-diameter inclined tubular girders of the yoke on trunnions that act as the pivotal bearings on which the tube tilts north or south in declination, as astronomers call it. The drawing opposite shows the trunnion on the west side with the tubular girder cut away to disclose internal structure.

In the upper portion of the drawing can be seen a large gear that is 14 feet in diameter, closely resembling the gear used to slew the instrument east and west as described on page 17. The hollow spindle extending to the left from this gear is secured to it by means of a large number of rod-like spokes resembling a bicycle wheel. The spindle engages the inner races of two large ball bearings whose outer races are held by a cylindrical cross member in the large inclined tubular girder. This trunnion, along with a similar one on the east side of the tube, permits the telescope tube to swing easily through a large angle from north to south.

The bicycle-spoke connection between the main tube and the trunnion is provided to absorb the effects of flexure in the heavy steel structure, allowing the ball bearings to operate smoothly in all positions of the telescope.

In front of the man in the center of the picture is a console housing an array of small motors and gear trains that provides slow motions for fine adjustment of the declination setting. The larger motor mounted at an angle to the trunnion is a one-horsepower unit working through the large gear to slew the tube into position when aiming the telescope. This gear and its associated gear train move the tube at a rate of 45 degrees per minute. A smaller motor provides a motion of $\frac{1}{2}$ degree per minute for final precise aiming. Still another motor and gear train move the tube only $\frac{1}{40}$ degree per minute for "guiding" out small errors resulting from atmospheric refraction or flexure in the instrument. Last of all there is a small motor and gear train whose rate can be adjusted by the astronomer to make the telescope tube move steadily at any desired slow rate in the north-south direction to make it follow the inherent motion of a comet, planet, the moon, or other object that is not fixed in space like the stars.

TWO HUNDRED INCH MIRROR, C.F.L. SUPPORT & COVER



CASSEGRAIN
FOCUS

$f' 16$

APPROXIMATE SCALE

0 1 2 3 4 5 6 FT.

RE-ENTER 37

The 200-Inch Mirror

A cutaway view of the bottom of the main tube showing the 200-inch mirror, covers, counterbalance supports, and the steel cell that secures the mirror to the bottom of the tube.

The heart of any telescope is the optical element that collects the light of faint objects and focuses it into an image that can be studied in various ways. In this instrument the collecting element is the 200-inch concave mirror. The thousands of other parts ranging from the smallest screw to the tons of steel and concrete that compose the mounting, foundations, and dome, all have a single purpose—to make it possible for the mirror to perform its function as efficiently as possible. To do this the telescope must be capable of pointing to any part of the sky. The structure that carries the mirror is designed to make this possible.

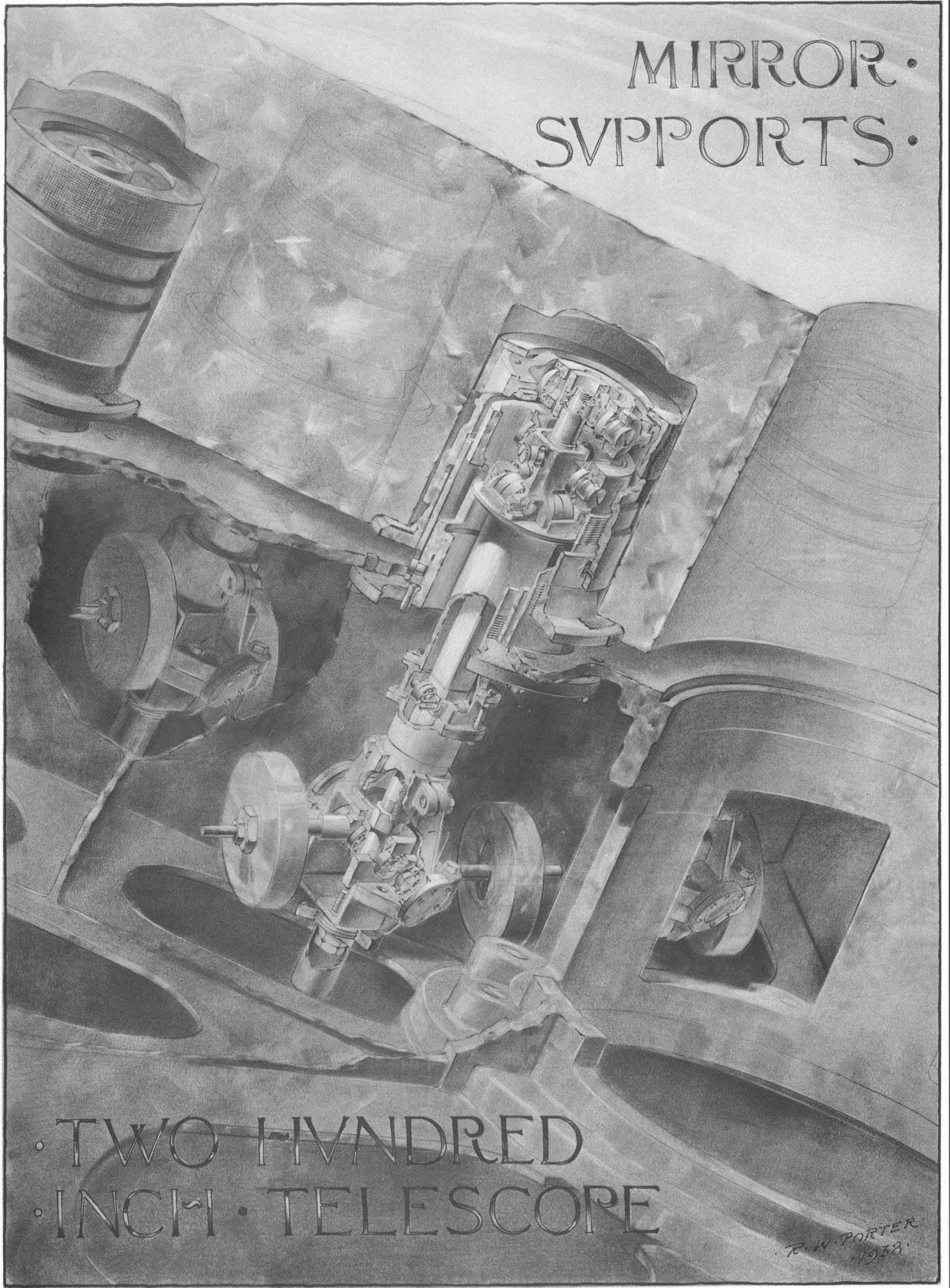
It may seem surprising that a mirror the size of the 200-inch, despite a thickness of nearly two feet, is not sufficiently rigid to maintain its shape to the prescribed accuracy of a few millionths of an inch when tilted in all positions. It tends to sag and warp from its own weight.

To overcome this difficulty the mirror was cast with recesses in the back to reduce its weight without reducing its rigidity, and 36 delicate counterbalance supports, as shown in the cutaway drawing at the left, were provided to hold the mirror at its center of gravity so that it will not distort, regardless of how it is tilted. (The operation of these counterbalances is illustrated and described on the following page.)

The delicate reflecting surface of the mirror must be protected from dust and possible damage when not in use. This is done by folding covers that close like the petals of a flower over the glass disk. In the drawing they are shown only partially opened. They are designed so that as they open or close they maintain a circular opening and can be used as an iris diaphragm for the mirror exactly like the iris diaphragm of a camera lens.

The central hole in the mirror and the long tube extending through it serve two purposes. The tube supports a diagonal flat mirror that will be described on page 39, while the hole provides a light path for starlight coming to a focus at the second observing position below the main mirror, known as the Cassegrain focus (page 37). In the drawing at the left light rays are shown coming to a focus on the slit of a spectrograph clamped to the steel cell below the mirror.

MIRROR.
SUPPORTS.



• TWO HUNDRED
• INCH • TELESCOPE

R. W. PORTER
1938

Mirror Counter-balance Supports

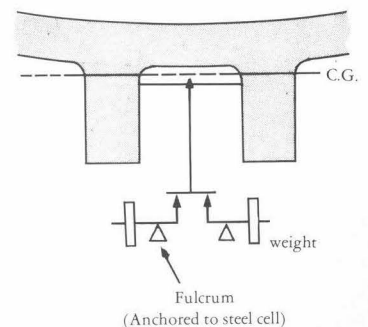
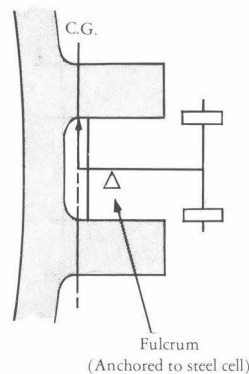
Thirty-six of these intricate double-acting counterbalance devices support the 200-inch mirror at its center of gravity to prevent distortion of the huge disk when it is tilted in different directions.

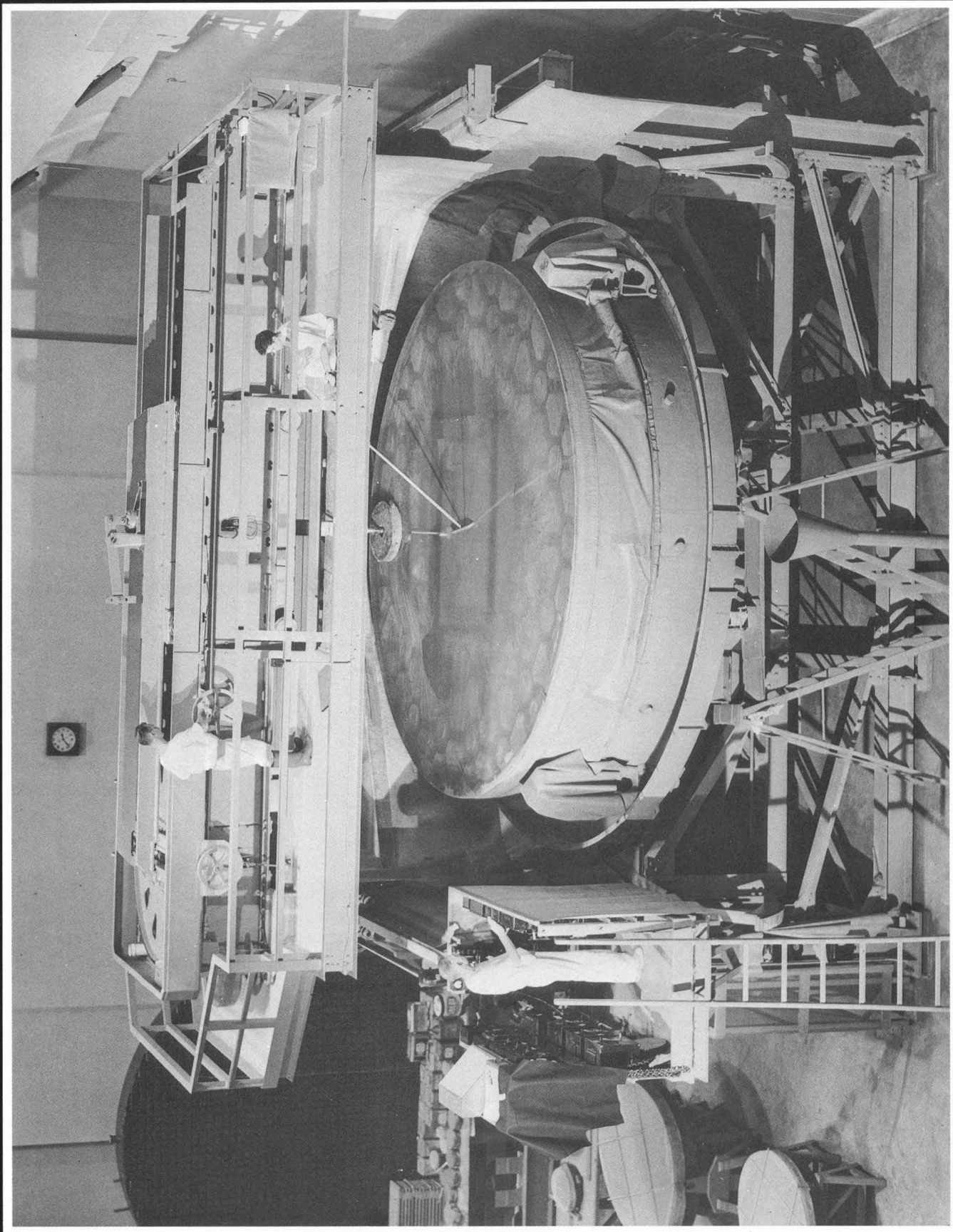
In this cutaway drawing of the mirror one of the counterbalance systems is seen in cross section. Too intricate to be described in detail, each support acts as two completely independent systems. The two basic principles of operation are illustrated below by simple diagrams.

In the first diagram the mirror is shown tilted up on edge. A lever arm with lead weights attached to one end pivots about a fulcrum that is supported by the steel cell, and applies an upward thrust on the insert anchored to the recess cast into the back surface of the glass disk. The lead weights are adjusted on each of 36 supports so that each one carries its share of the load; collectively they exactly counterbalance the total weight of the glass disk. By supporting the weight of the disk inside the recess at its center of gravity, there is little tendency for the mirror to sag out of shape.

The second diagram shows how these same devices are made to perform a different function when the mirror lies face upward. The two lead weights, on individual lever arms, work about pivots that were inactive in the previous case. They now thrust upward against the end of the central shaft. This shaft runs smoothly through bearings to transmit this upward thrust to the insert anchored in the recess of the mirror. The lead weights on all supports are adjusted to exert the right amount of upward thrust to carry their share of the weight of the mirror, and collectively to support its full weight.

When the telescope is tilted to any intermediate angle these two independent lever actions work simultaneously, each providing just the right amount of thrust in its direction of motion to float the mirror free from any strain or distortion. Such an intricate support system had never before been tried, but has proved eminently successful with the 200-inch mirror.





The 200-Inch Pyrex Disk on Its Grinding and Polishing Machine

Eight years of work were expended in meticulous grinding and polishing to produce the highly accurate surface required for the mirror.

Unlike household mirrors, telescope mirrors reflect light from their front surface rather than the back to avoid detrimental effects on light rays that would result from their passage through the glass.

In order to collect into a sharp focus all light falling on its surface, the mirror must have a concave parabolic curvature accurate to less than $1/4$ wavelength of light, or a few millionths of an inch. This saucer-like shape was achieved by grinding more glass from the center of the disk than from the edge. In the case of the 200-inch disk, $4\frac{3}{4}$ tons of glass were removed. After this "rough grinding" operation, finer and finer grades of abrasive were used to perfect the surface. Finally, polishing powder—red oxide of iron— and a wax-coated tool were used to produce the high polish required for an efficient mirror. Then began the long and critical job known as "figuring," in which errors in the shape of the mirror surface were removed by careful local polishing.

Because the large grinding and polishing tools used on the 200-inch mirror weighed hundreds of pounds and required great power to move them to and fro over the glass disk, powerful machinery was required. In the photograph at the left is shown the 200-inch disk lying face-up on the table of the special machine built in the optical shop on the campus of the California Institute of Technology to grind and polish the huge mirror. As the disk was slowly turned, the grinding or polishing tool was driven in the desired path by the upper movable section of the machine, under the control of the man in the booth at the left. The two men on the bridge performed other duties such as adjusting the "stroke" of the machine, and feeding abrasive or polishing powder and water to the tool.

In the photograph a very small polishing tool was in use in order to concentrate the polishing action on a local area that was slightly higher than it should be. By such local polishing and frequent testing, the surface was brought closer and closer to conformity with the required curvature. In final stages of this "figuring," errors of a few millionths of an inch were removed. Highly specialized methods of testing were required to disclose such small errors. The final corrections were made by hand at Palomar.



Final Corrections of the 200-Inch Mirror Surface

An expert optician using very small polishing tools removed the last tiny errors from the mirror surface while it rested beside the telescope in the dome on Palomar Mountain.

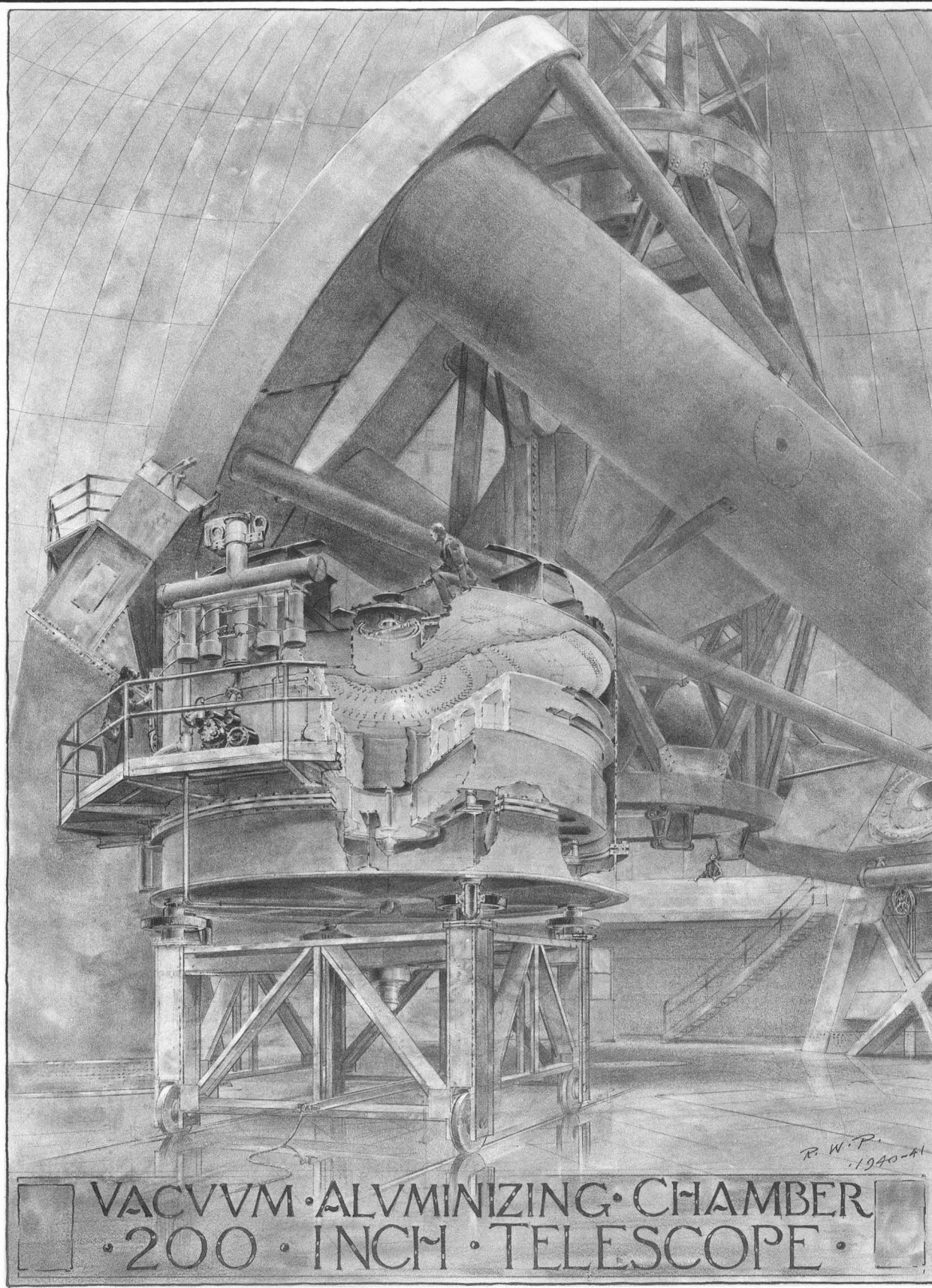
In the optical shop at Caltech in Pasadena, where most of the grinding and polishing was done on the mirror, it was possible to test the accuracy of the surface only with the disk tilted into a vertical position. Since it would never actually be used in that position, no final decision regarding its performance could be made until the disk had been placed in the telescope and tested on real stars. Hence, the final corrections were made with the mirror in the dome on Palomar Mountain.

The methods of testing, using light rays, were so delicate that inequalities in the reflecting surface no larger than a few millionths of an inch in height were easily detected. Any areas that were slightly too high required additional local polishing, but if this work were not done at exactly the right places, mistakes could be made that would require months or years of work to correct.

To assist the optician in accurately identifying areas requiring additional correction, markers were affixed to the mirror surface from which measurements could be made. These markers can be seen in the picture at the right. The honeycomb of recesses cast into the back of the glass disk to reduce its weight are also clearly visible.

The man in the picture is the expert optician who made the final, delicate corrections by hand, using small polishing tools sometimes no more than an inch square. In the last stages he would polish for only a few minutes, then await the results of optical tests on stars that sometimes required two or three nights to complete. Then he would polish a little more, and again the mirror would be tested. After more than a year of such meticulous work the surface was judged to be sufficiently accurate.

However, the giant disk was not yet a mirror; it reflected no more light than a pane of window glass. To convert it into a brilliantly reflecting mirror that could capture the faint light of distant galaxies, one more delicate operation was required. This is described on the following page.



VACVUM · ALVMINIZING · CHAMBER
· 200 · INCH · TELESCOPE ·

The Aluminizing Chamber

To convert the polished surface of the glass disk into a mirror capable of reflecting a high percentage of the light falling on it, a film of aluminum is deposited on the glass in a high-vacuum tank.

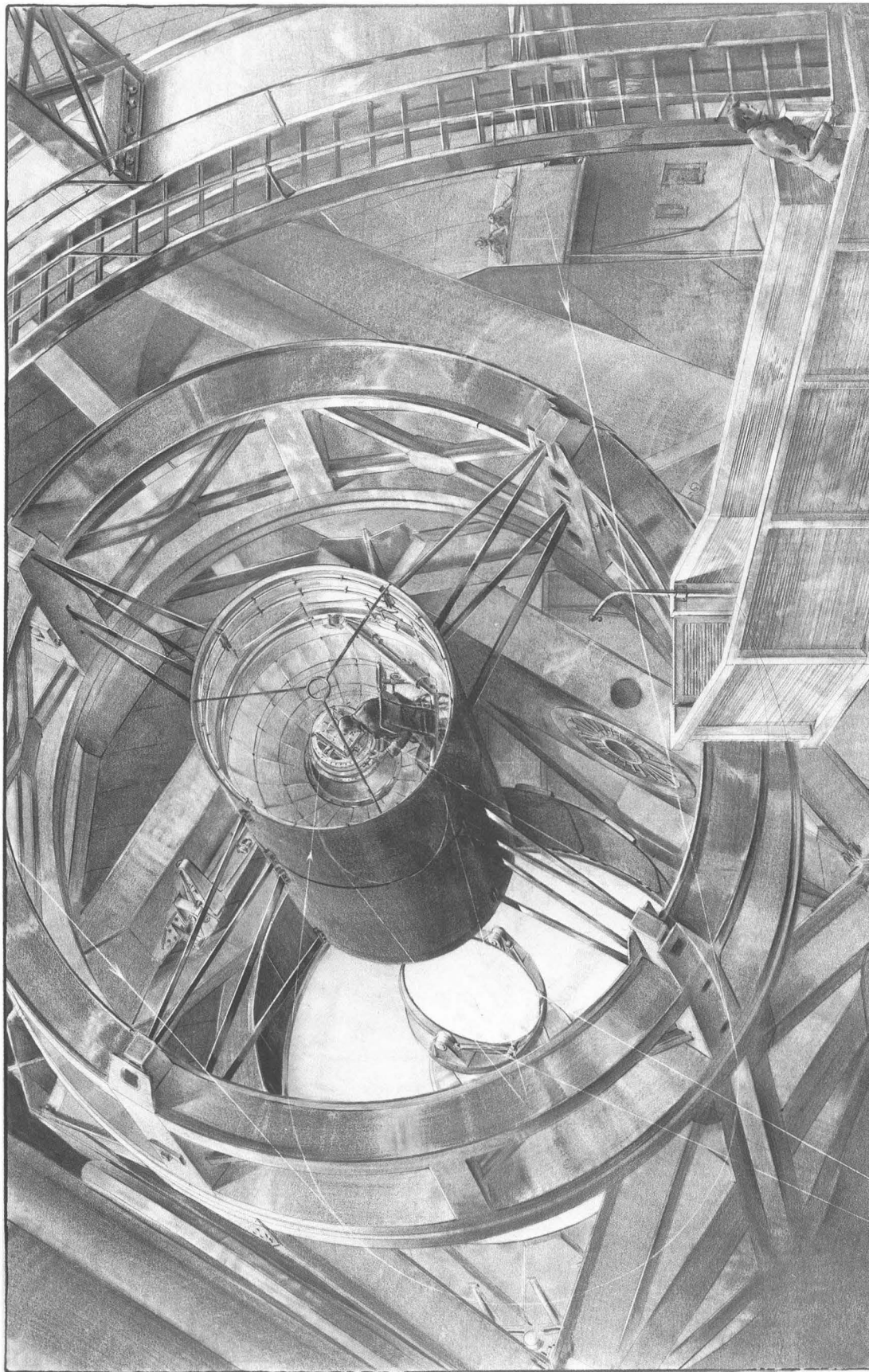
The bare surface of the polished disk reflects only about 4 percent of the light falling on it and so must be made more efficient before it will be of use in a telescope. Until 1936 a chemically deposited film of silver was used for telescope mirrors, but silver tarnishes so rapidly that it must be replaced at least twice a year. Then, in 1936, a new process was developed by which aluminum could be evaporated onto glass in a high vacuum, producing more efficient mirrors that would last for years.

To yield a highly reflecting surface the aluminum must be applied in an airtight chamber from which virtually all of the air has been removed. To achieve this, a special steel tank was constructed for the 200-inch mirror that would enclose both the glass disk and its supporting steel cell. It had to be strong enough to withstand tons of air pressure exerted on it by the surrounding atmosphere when the near perfect vacuum was obtained inside the huge container.

The drawing at the left shows the large steel tank in cut-away section, standing beside the 200-inch telescope. The mirror and its steel supporting cell are shown enclosed in the tank. In the roof of the tank above the mirror are numerous coils of tungsten wire, the same metal used for the filaments of electric light bulbs. On these filaments are placed small loops of pure aluminum wire. After the air has been pumped from the tank these filaments are raised to incandescent heat by the application of a large electrical current. The aluminum wire melts and then boils off the filaments, diffusing rapidly in all directions. It adheres to any surface that it encounters, coating the entire inside of the tank, and especially the mirror, with a brilliant film of aluminum. When all filaments have been fired and the required amount of aluminum deposited, air is admitted to the tank, and it is lifted off. An inspection of the mirror is made and, if found satisfactory, the mirror and its cell are replaced in the telescope. The entire operation can be performed in about two days.

To facilitate the handling of the mirror and cell, weighing a total of 60 tons, the lower portion of the aluminizing tank is supported on a frame that is carried on steel wheels running on tracks laid in the cement floor of the dome. This entire assembly, with the tank removed, can be rolled to a point directly below the mirror cell. Screw jacks in the legs of the stand, operated by powerful electric motors, raise the baseplate of the tank until it engages the mirror cell. Bolts securing the cell to the end of the telescope are removed, and the screw jacks reversed, lowering the mirror and cell out of the telescope. The assembly is wheeled to one side, the old aluminum film chemically removed, the disk thoroughly cleaned, the tank with its array of loaded filaments lowered over the mirror, the vacuum seals made air tight, and the vacuum pumps turned on.

This process is repeated whenever the reflectivity of aluminum coating is significantly reduced.



THE PRIME FOCUS.

TWO HUNDRED INCH TELESCOPE

R.M.P. 1934

The Prime-Focus Observing Capsule

The astronomer rides in the capsule at the top of the telescope when taking photographs or using other equipment at the prime focus of the telescope.

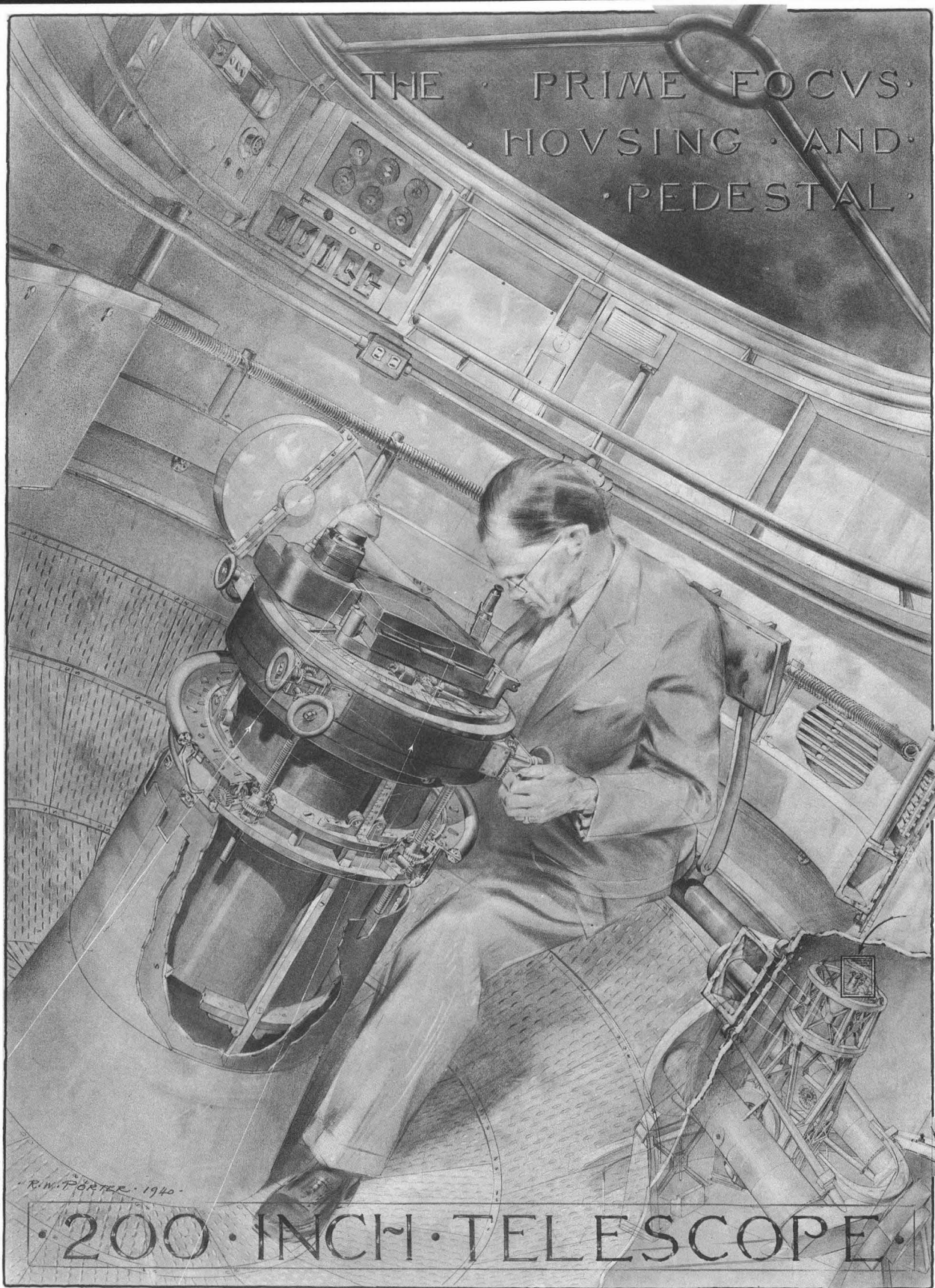
The view at the left is from a point near the base of the dome shutters and shows the telescope tilted far down toward the horizon. At the lower right is the elevator that rises along the curve of the dome at the edge of the slit. By raising or lowering this elevator and rotating the dome the astronomer is able to reach the top of the telescope tube wherever the instrument is pointing, and can step across into the observing capsule. A special seat can be adjusted to remain level regardless of how the telescope is moved about.

It may seem that the prime-focus capsule obstructs a large amount of light, suspended as it is in the middle of the tube. However, the images formed by the main mirror must reach the instrument somehow, and the only alternative would be to insert a diagonal mirror in place of the capsule to reflect the light out to the side of the tube. It then becomes a question of which obstructs more light, the diagonal mirror or the capsule. The answer depends upon the optical characteristics of the telescope. In the case of the 200-inch, the capsule is preferable.

Rising from the floor of the capsule is a hollow pedestal on top of which can be clamped a photographic plateholder, a spectrograph, or a photometer. Light from an astronomical object is focused by the 200-inch mirror—the large, bright disk seen at the bottom of the tube in the drawing—up through the pedestal to a photographic plate or to some type of special instrument used for astronomical research. When the 200-inch telescope was built, one of its principal functions was to obtain photographs of faint celestial objects. This is still an important use of the telescope, but the development of new, sophisticated, and more sensitive detectors has greatly extended its reach, allowing astronomers to detect faint objects and to work at infrared and near-radio wavelengths of light.

In the early days of the 200-inch telescope, the astronomer would ride in the prime-focus capsule to expose a photographic plate or to operate other types of instruments. This practice is becoming less common, for the new instruments used with the telescope include remote control units that permit the astronomer to operate from the comfort of the telescope control room.

THE · PRIME · FOCUS ·
HOUSING · AND ·
PEDESTAL ·



R. W. PORTER · 1940 ·

· 200 · INCH · TELESCOPE ·

"Observing" in the Prime-Focus Capsule

An astronomer is shown seated in the adjustable chair with a photographic plateholder locked to the pedestal, and his eye at the guiding eyepiece. Exposures range from a few minutes to several hours.

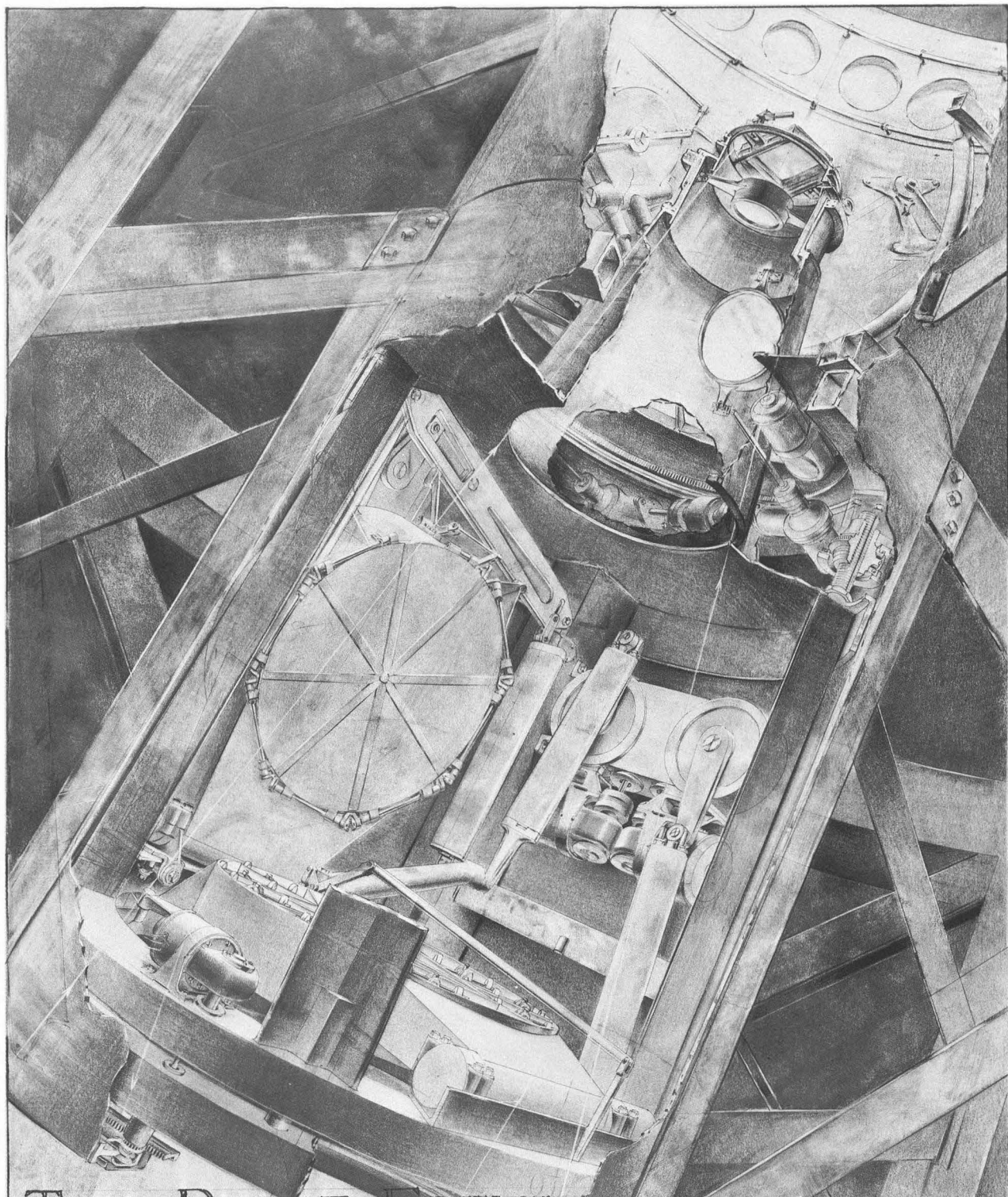
Although modern astronomers no longer engage in observing objects by eye, the old term "observing" still is used in connection with all types of photographic and photoelectric work. It was explained in the introduction why it is a waste of an astronomer's time to look through a telescope.

The inside of the prime-focus capsule is shown at the left with an astronomer as he might appear while exposing a photographic plate, except that everything would be totally dark, of course. Rising from the floor of the capsule is a hollow pedestal through which the light rays from the 200-inch mirror converge to a focus on the photographic plate.

Slight displacement of the images on the plate can be caused by refraction of the earth's atmosphere on the light rays, by small flexures of the telescope structure, or by slight errors in the clock-drive system. These must be corrected instantly if the photograph is to be clear and sharp. To make it possible for the astronomer to detect such errors, a microscope is clamped alongside the plateholder and a star image is centered on a crosswire in the eyepiece. Any tendency of the image to wander from the crosswire is immediately corrected by the astronomer, making use of push-buttons that operate small motors that introduce corrections in the position of the telescope. This operation is known as "guiding."

The astronomer's seat will travel completely around the capsule and tilt through a large angle to compensate for any position to which the telescope may be tipped. Dials on the wall above the astronomer's head tell him exactly where the telescope is pointed, and switches below permit him to activate essential equipment.

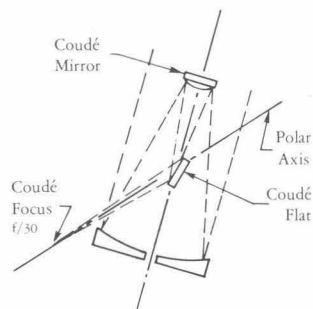
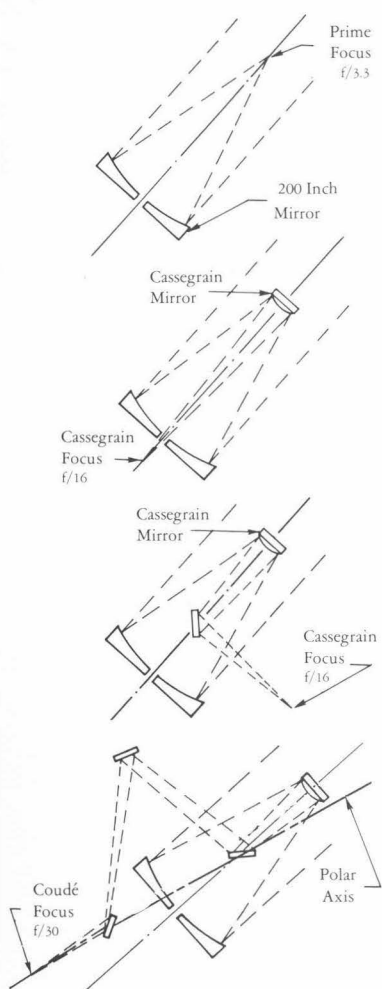
On occasions the plateholder is removed and a spectrograph set in place, permitting the spectra of faint objects to be recorded. If he wishes to measure with great precision the relative brightnesses and colors of objects, the astronomer installs a photoelectric photometer whose output is fed through sensitive amplifiers and thence into electronic computers right in the dome that analyze the measurements as fast as they are gathered. Such computers accomplish more accurately in seconds what astronomers required weeks to do by older methods.



THE PRIME FOCVS
CASSEGRAIN & COUDE MIRRORS. R.W.P.
TWO HUNDRED INCH TELESCOPE. 1938

Cassegrain and Coudé Secondary Mirrors

This cutaway drawing shows the lower section of the prime-focus capsule, which contains the interchangeable convex secondary mirrors used to increase the focal length of the telescope. Sketches below show the different light paths.



The focal length of the main mirror of a reflecting telescope is determined at the time it is ground and polished; it is known as its "prime" focal length. In the case of the 200-inch mirror this is 660 inches with an optical speed of $f/3.3$; that is, the focal length is 3.3 times the mirror diameter. It produces an image of the moon about 6 inches in diameter.

The focal length of the telescope can be increased by inserting a convex mirror just ahead of the "prime" focus. Two different convex mirrors are provided in this telescope. One of these, known as the Cassegrain mirror, after the man who devised the system, shifts the focus to a point just below the main mirror, which has a hole in its center to permit the light rays to reach a photographic plateholder or spectrograph clamped to the back of the mirror cell. The effective focal length of the telescope is then 3200 inches and the optical speed is $f/16$. An image of the moon at this focal point is nearly three feet in diameter.

Another convex mirror is available that gives the 200-inch telescope an effective focal length of 6000 inches with an optical speed of $f/30$. Diagonal flat mirrors are required in this system to fold the light rays so that they can be sent down through the hollow south polar axis of the telescope into the constant-temperature room in the solid lower portion of the dome. Because of the angle through which the light is bent, this system is called the "coudé," a French word meaning elbow. At this focal length the image of the moon is nearly five feet in diameter.

The drawing at the left shows these two auxiliary mirrors located in the lower end of the prime-focus capsule. One is shown lowered into operating position while the other is folded back into its recess in the capsule wall. Either one can be lowered into position as required, or both can be removed entirely from the light path when work is to be done at the prime focus.

The sketches at the left illustrate the different light paths provided by these combinations of convex mirrors and diagonal flats that direct the rays to the desired observing positions. See also the drawings on pages 36, 38, and 40 to see these various foci in use.

THE 200 INCH TELESCOPE LOOKING EAST

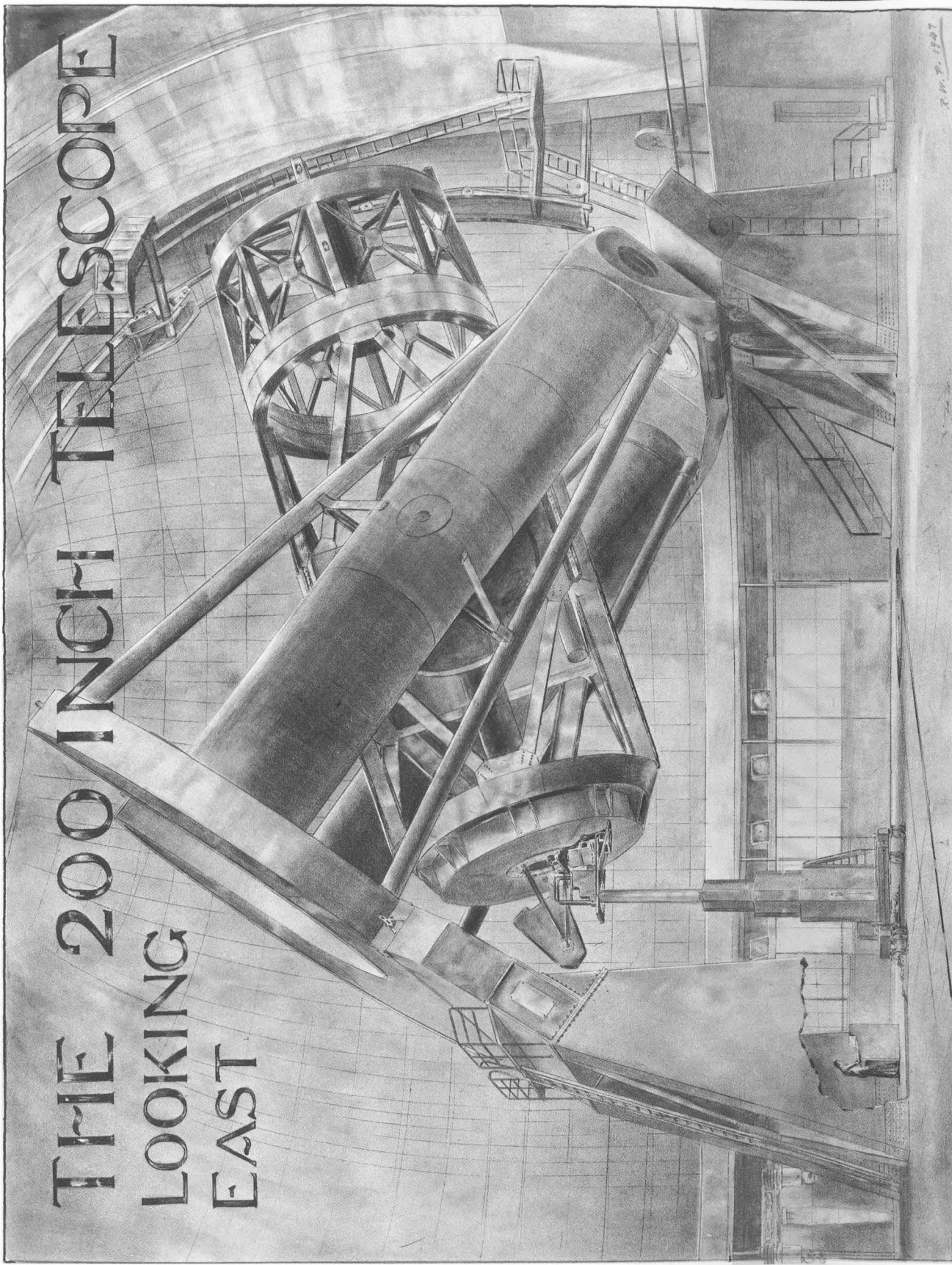


PLATE 107

The Cassegrain Focus in Operation

The view at the left shows the 200-inch telescope being used at the Cassegrain focus by an astronomer atop an elevating chair.

At the Cassegrain focus astronomers use heavy and complex instruments such as photometers and spectrometers, depending on the type of problem they are investigating. These pieces of equipment are attached to the steel cell that holds the main mirror to the bottom of the tube.

To operate this equipment the astronomer had to be raised to varying heights. He also had to be able to shift his position east and west to follow the motion of the telescope as it tracked the stars. This was made possible by a special electrically operated chair that could be raised or lowered, or driven about over the concrete floor of the dome. Push buttons and a small steering wheel provided the astronomer with the controls he needed to maneuver the machine about and adjust its height as he worked.

The picture at the left shows an astronomer seated in the chair atop the elevator shaft of the movable platform. Wheels at the corners of the platform were electrically driven and all four swiveled simultaneously in response to the steering wheel on the control panel beside the astronomer.

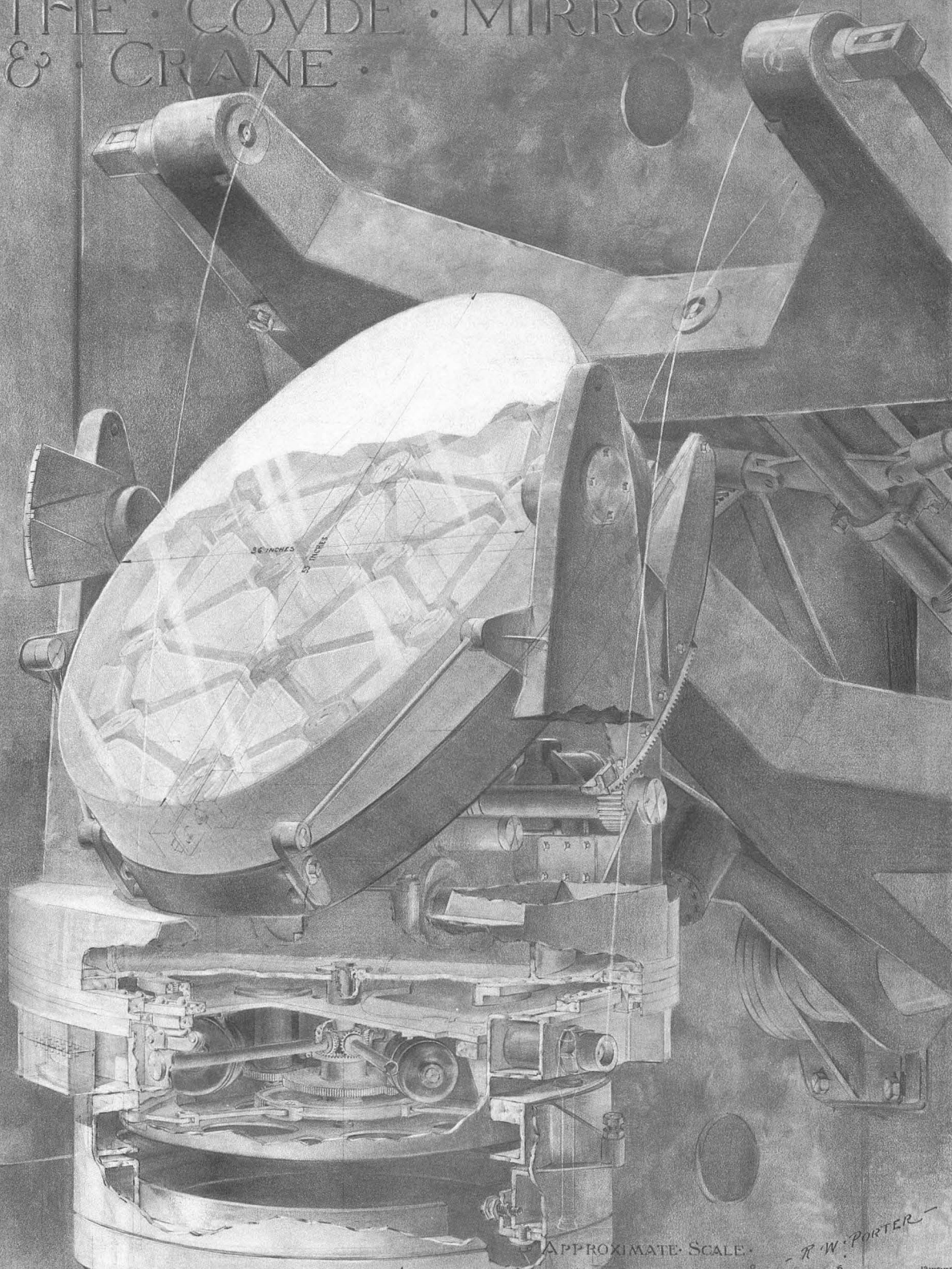
The operator had to use extreme care to avoid bumping into the telescope in the dark, or allowing the telescope to bump the chair as it moved slowly while tracking the stars. Usually no lights are permissible during working hours, so it required skill and constant attention to operate both the telescope and the observing chair.

Because of these difficulties and hazards, this observing chair was replaced by another that was fastened directly to the mirror cell so that the astronomer could ride with the telescope. Of similar design to the adjustable chair in the prime-focus capsule, but electrically operated, this seat allowed the astronomer to remain on an even keel at all times, and to move about the plateholder or spectrograph as required to make adjustments. As protection against any possibility of falling, and to prevent accidental dropping of objects, the seat was completely surrounded by a strong wire mesh screen.

Recently, sophisticated television cameras and remote controlled instruments have been mounted at the Cassegrain focus to permit the astronomer to observe from the telescope control room on the observing floor. The wire-mesh cage remains in place at the Cassegrain focus for servicing and adjusting the instruments.

The drawing at the left gives a good impression of the tremendous size of the 200-inch telescope when it is compared to the size of the man atop the elevating chair, or the one at the control desk, visible through the cutaway section of the pier below the horseshoe bearing.

THE COVDE MIRROR
& CRANE



APPROXIMATE SCALE

R. W. PORTER

1/4 INCHES
3 FT.

TWO HUNDRED INCH TELESCOPE

The Cassegrain-Coudé Diagonal Mirror

Mounted in line with the declination trunnions, this diagonal flat mirror reflects the image formed by the main mirror either into the yoke girder or down the south polar-axis to the coudé spectrograph room.

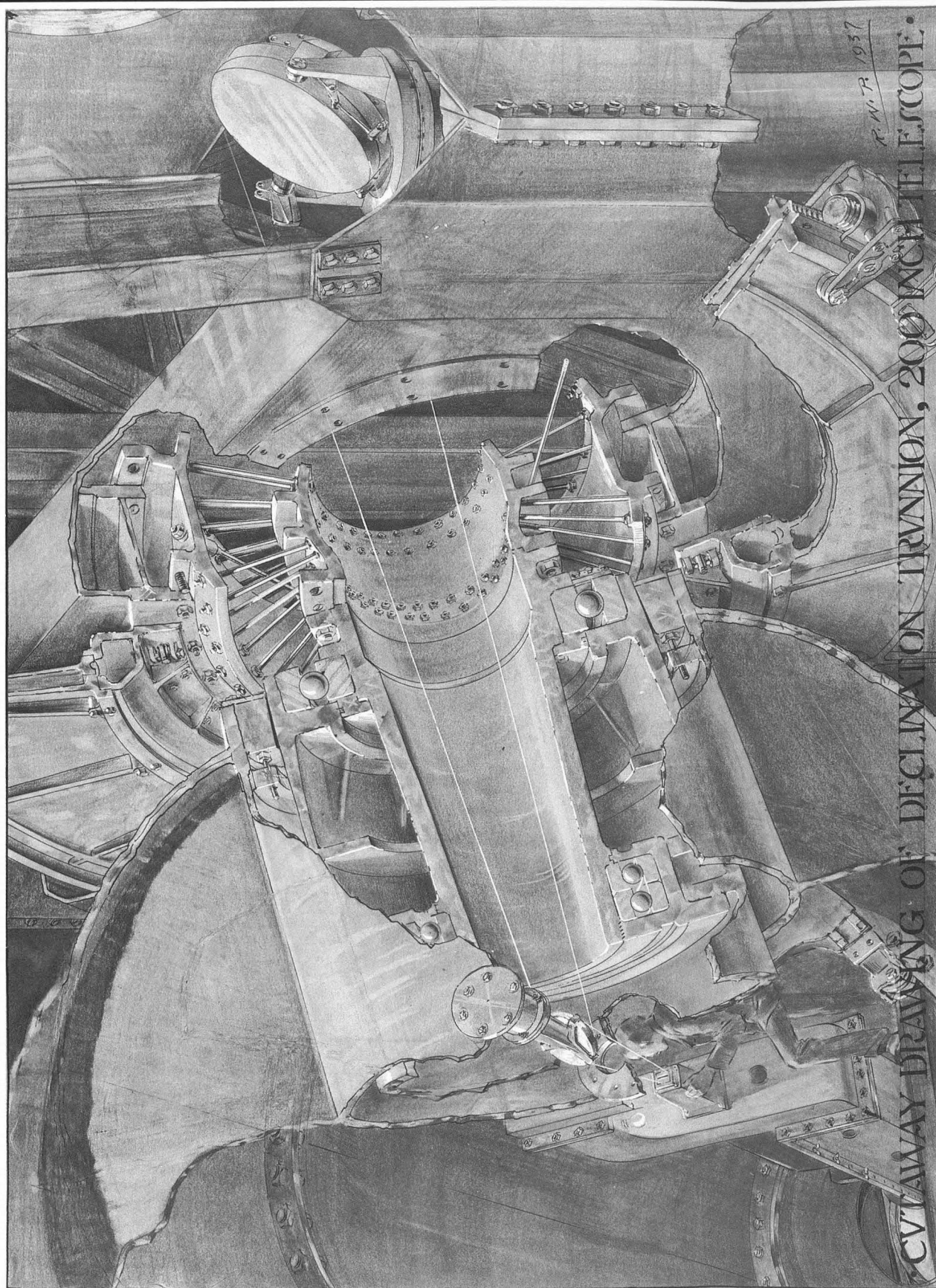
In the discussions of the Cassegrain and coudé secondary mirror systems, mention was made of a diagonal flat mirror that could be used to reflect the Cassegrain image through 90 degrees into the tubular girder of the yoke, or to send the coudé image through the south polar-axis into the coudé room. The cutaway drawing at the right shows this mirror in detail. Its upper surface is optically flat within a fraction of a wavelength. Its back is cellular, like all other mirrors in the telescope, to reduce weight without loss of rigidity. The drawing shows part of the reflective aluminum film removed to reveal the recesses.

This mirror is mounted on top of a tube extending upward from the steel cell that supports the 200-inch mirror, passing through the hole in the mirror provided for the Cassegrain focus. The location of this supporting tube and mirror is best seen in the drawing on page 6.

An electrically operated fork, visible at the upper right, descends until two pins at the end of the fork are accurately aligned with sockets in the base of the mirror mount. The pins lock into the sockets, then the clamps securing the mirror mount to the top of the vertical tube automatically unlock. Electrical and mechanical connections disengage, and the forklike crane slowly swings the mirror and cell up and back into a special housing in the side of the telescope tube. An exact reversal of this sequence installs the mirror on the pedestal when it is needed.

All of these operations are electrically interlocked so that the next one cannot begin until the previous one is safely completed. In the event of failure of any step in the sequence, all action stops immediately and a warning signal is given to notify the operator. This makes it impossible for any portion of the mechanism to be damaged or for the mirror to fall off its pedestal, or be dropped by the forklift.

When this mirror is used on the coudé system, the angle at which it is tilted depends upon the angle of tilt of the telescope tube in the north-south direction; the mirror must tilt one-half as much as the tube if it is always to reflect the light rays down the south polar-axis. If the main tube is tilted far to the north, this diagonal can no longer send all of the light to the coudé room, and two more flat mirrors, one on the arch (shown in the upright position in the drawing on page 6) and another at the entrance to the south polar-axis, are put into operation.



P. No. 7 1937

CUTAWAY DRAWING OF DECLINATION TRUNNION, 200 INCH TELESCOPE.

The East Declination Trunnion

Besides housing the ball bearings and bicycle-spoke flexure compensator, the east trunnion is equipped with a mirror to direct light to instruments mounted in the tubular girder of the yoke.

The east and west trunnions are very similar as regards the supporting ball bearings, spindles, and flexure compensators. The major difference is in the auxiliary equipment. The space around the western trunnion, described on page 19, is devoted to electrical and mechanical units involved in the movement of the telescope in the north-south direction. The area around the eastern trunnion, on the other hand, is reserved for spectrographs, photometers, and other equipment required by astronomers.

Starlight is directed into the east arm by a combination of mirrors, as shown in the drawing at the left. The light beam, indicated by white lines, passes through the hollow trunnion spindle to another smaller diagonal flat mirror that sends the beam longitudinally down the tubular girder to instruments mounted below.

A set of steps leading up the inclined tubular east arm of the yoke allows astronomers to ascend to the instruments without difficulty. Their weight is compensated by adjustment of counter-balance weights in the telescope structure. To allow for the wide range of positions to which the telescope may be set, and for the constantly changing position of the telescope during an exposure as it follows the motion of the stars, the entire stairway is mounted on ball bearings that permit it to roll inside the tubular girder. As a result, it always remains at the bottom of the tube as the telescope rotates, providing the astronomers with level, secure footing at all times.

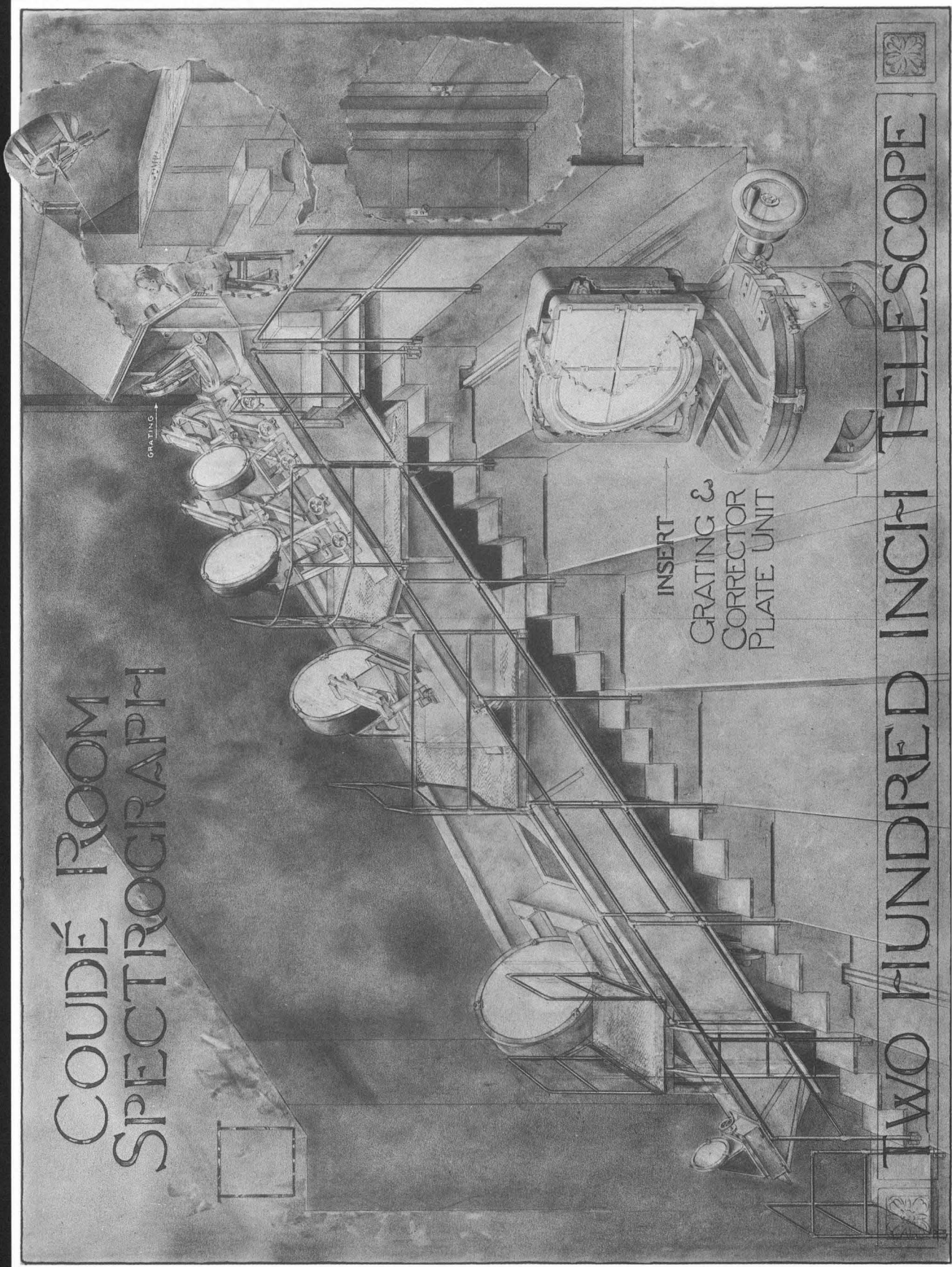
Pictures like the one at the left give some idea of the enormous complexity of the 200-inch telescope. When you see the number of different parts that go into just one small section, an appreciation develops for the magnitude of the project. It becomes easy to understand why 20 years were consumed in engineering and building the giant instrument.

COUDÉ ROOM SPECTROGRAPH

TWO HUNDRED INCH TELESCOPE

GRATING

INSERT
GRATING &
CORRECTOR
PLATE UNIT



The Coudé Spectrograph Room

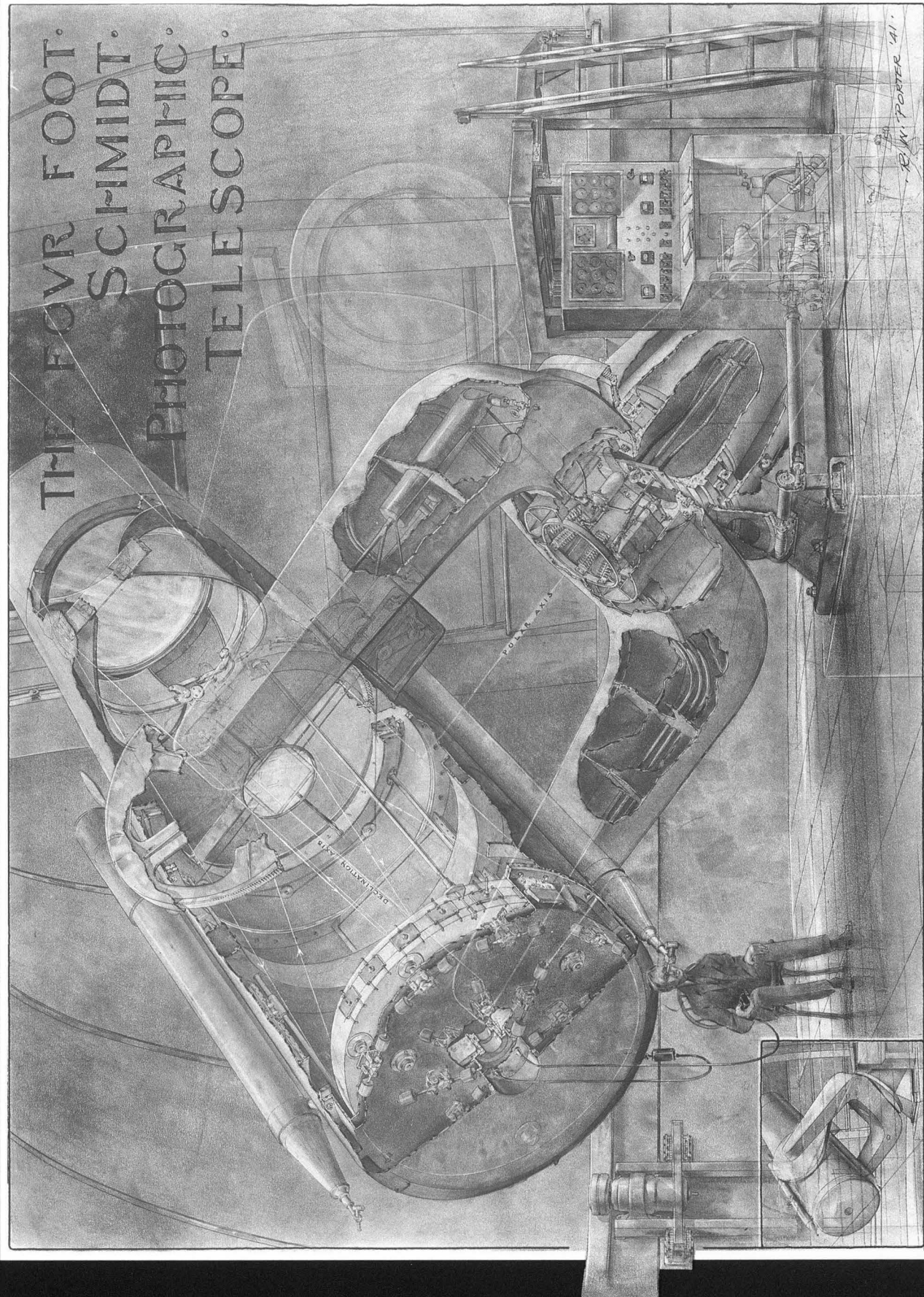
Containing four spectrograph mirrors of different focal lengths, the constant temperature room is completely light-tight, and serves as a camera. The astronomer chooses the mirror with the focal length he requires and rolls it into the light beam on its carriage.

Reference has been made to the constant-temperature coudé room in the lower concrete section of the dome. The drawing opposite shows the interior of this room. At the upper righthand corner of the picture can be seen the end of the telescope's south polar axis through which the starlight is directed by the coudé combination of mirrors. A beam of starlight represented by a white line is shown coming from the end of the polar axis and passing just above the head of an astronomer. All of the light collected by the 200-inch mirror is focused onto a slit directly in front of the seated figure. After passing through the slit the light diverges downward to a 12-inch mirror at the extreme lower left. This mirror renders the rays parallel and redirects them upward to the assembly marked "grating" just to the left of the slit. An enlarged view of this grating is shown as an insert at the lower right.

A grating is an optically flat piece of glass with a highly reflective aluminum film on its surface into which have been ruled many thousands of parallel grooves—10,000 to the inch in the case of the grating used at the 200-inch coudé spectrograph. These fine grooves break up the incident light into a spectrum or rainbow of its constituent colors. The grating reflects this spectrum downward at an angle. The astronomer selects the camera mirror with the focal length that best suits his or her requirements and rolls that mirror, on its wheeled carriage, into the beam of light coming from the grating. That mirror focuses the spectrum onto a variety of light-sensitive detectors held by a special device that permits all necessary focal and alignment adjustments. The length of the spectrum that is recorded depends upon the focal length of the camera mirror and the characteristics of the detector.

The spectrograph cameras operate on the Schmidt principle (page 45) that calls for correcting plates in combination with the mirrors. These correcting plates are mounted directly over the grating and serve all camera mirrors except the longest, whose focal length is 12 feet.

THE FOUR FOOT. SCHMIDT. PHOTOGRAPHIC. TELESCOPE.



The 48-Inch Schmidt Telescope

This Schmidt-type telescope is capable of photographing large areas of the sky with relatively short exposures. The corrector plate at the upper end of the tube is 48 inches in diameter, the mirror at the bottom is 72 inches.

The optical principle upon which this telescope is designed was discovered by Bernhard Schmidt in Germany in the 1930's. It constituted the first basic improvement in telescope design in over 300 years.

Although reflecting telescopes—those using concave mirrors—have several important advantages over refractors—those employing lenses—they have one very serious drawback. Reflectors produce sharp images only over a small angular field when they are designed with high optical speed (that is, a small f /ratio).

Schmidt's discovery involved the combination of a spherical mirror and a special thin lens located at the center of the curvature of the mirror. Called a corrector plate, this lens has a peculiar curve polished into it that completely eliminates the aberrations of the mirror. Excellent images are produced over a wide angular field at relatively high optical speed. The 48-inch telescope, at an optical speed of $f/2.5$, covers an angular field of 7 degrees, an area of the sky equivalent to 200 full moons. This is of great advantage to astronomers when they wish to photograph large areas of the sky.

The picture at the left is a cutaway drawing of the 48-inch telescope showing the corrector plate at the top of the tube followed by a "clam-shell" shutter directly below it. Halfway down the tube is the photographic plateholder that accepts plates up to 14x14 inches in size. At the bottom of the tube is the 72-inch mirror. The mirror must be larger than the corrector plate to give equal illumination to all parts of the photographic plate. With this type of design it is impossible to guide the telescope by using a star image alongside the plateholder, as is done with the 200-inch. Auxiliary guidescopes are provided for this purpose, one on each side of the tube. Each is a 10-inch refractor, beautiful instruments in their own right.

The Schmidt principle has been applied to many optical systems. We have already seen its use in the coudé spectrographs of the 200-inch telescope, and most of the other spectrographs used at the prime and Cassegrain foci also make use of the principle in order to increase their image quality and speed.

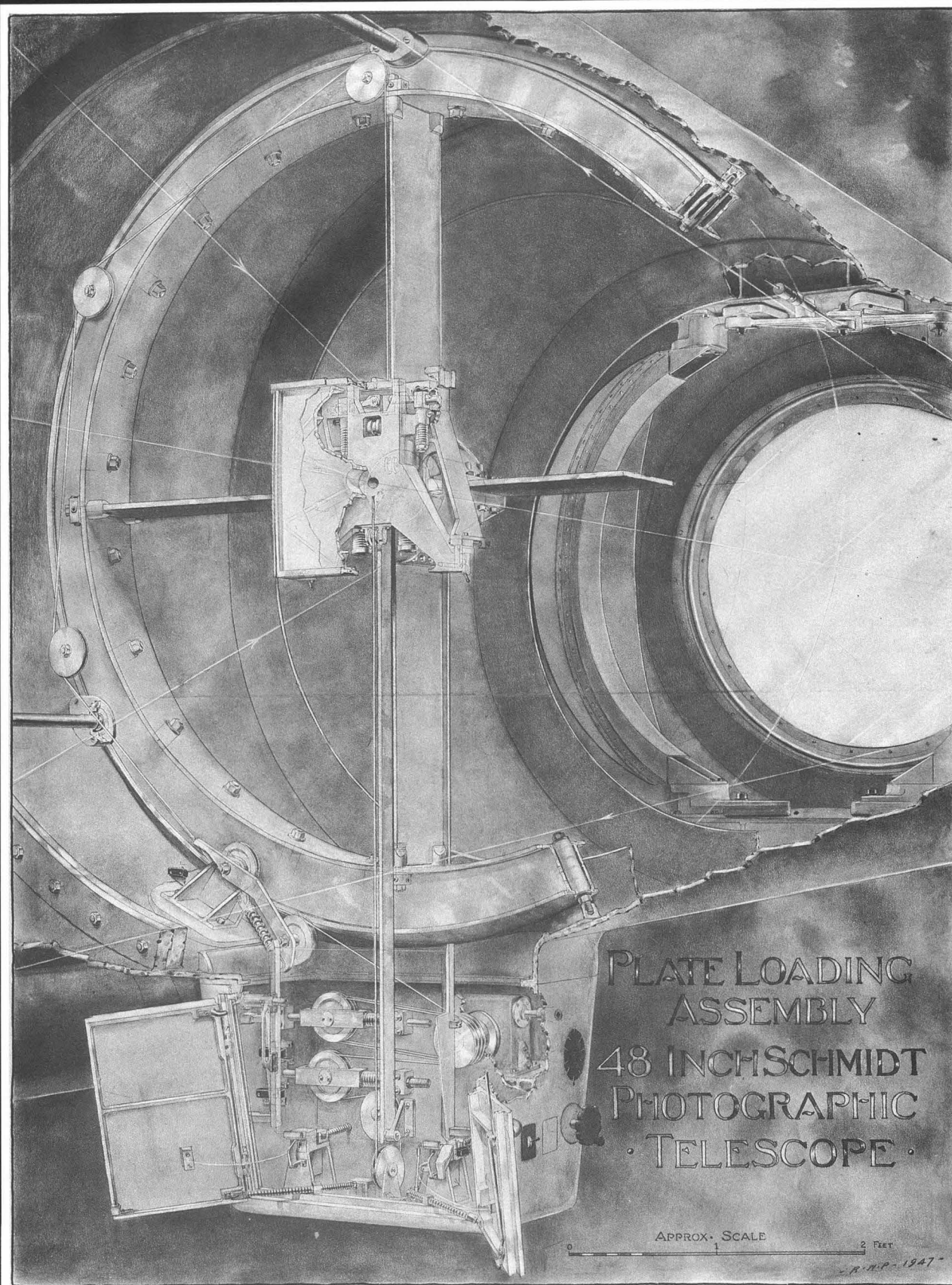


PLATE LOADING
ASSEMBLY
48 INCH SCHMIDT
PHOTOGRAPHIC
TELESCOPE

APPROX. SCALE

0 1 2 Feet

R.M.P. 1947

The 48-Inch Telescope's Plate-Loading Mechanism

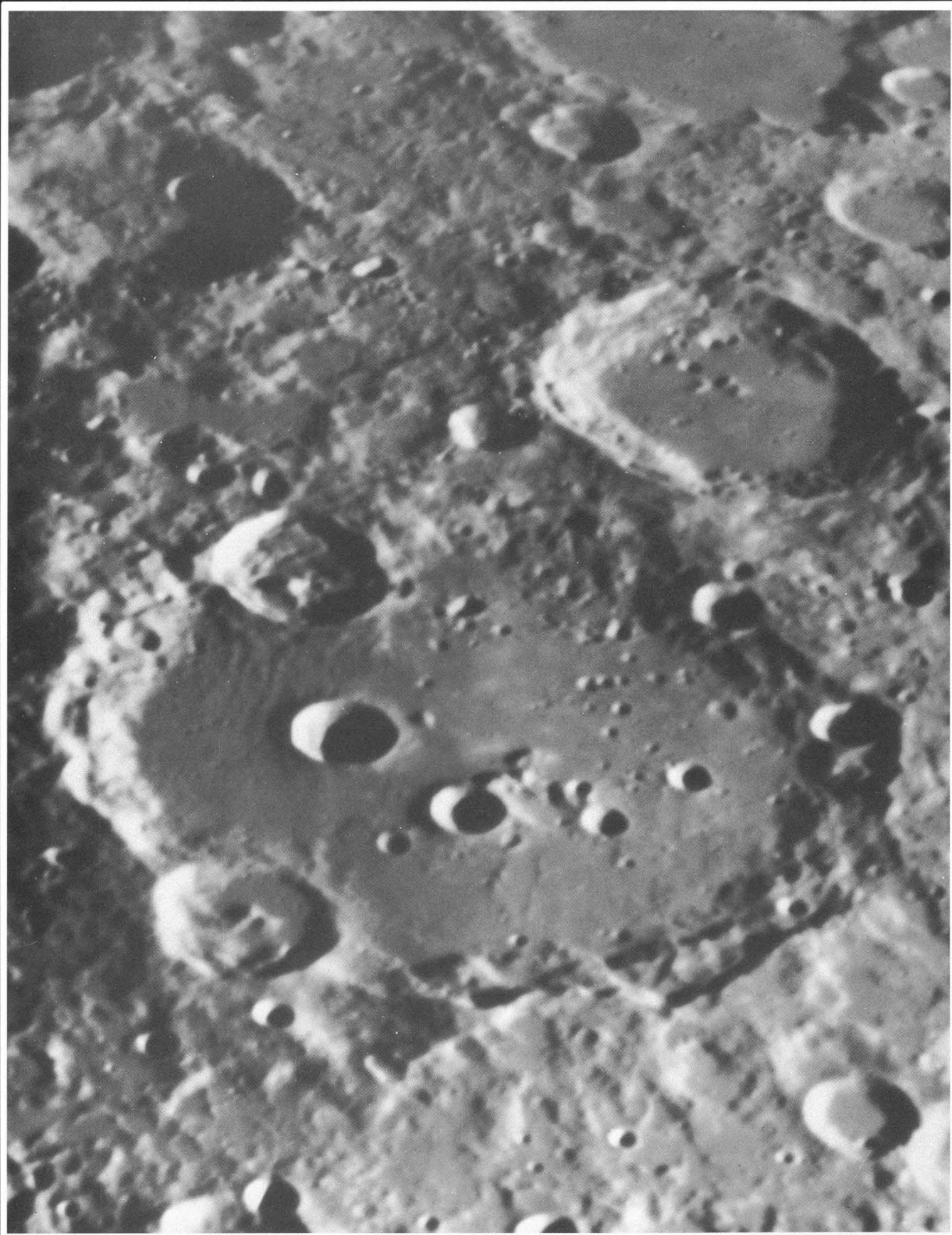
Plateholders capable of holding 14-inch square plates are heavy and would be difficult to place in position in the center of the telescope tube, so a mechanical device performs the task.

The images formed by a Schmidt-type telescope lie on a spherically curved surface. This requires that the photographic plate be bent to that exact curvature if sharp images are to be recorded over the entire field. To bend 14-inch square plates requires considerable force and to maintain them at that curvature requires strong plateholders that are unavoidably heavy. The astronomer is saved the task of lifting them into position by an ingenious mechanical elevator shown in the drawing at the left.

At the bottom of the picture can be seen a metal box with the doors open. With the telescope in its loading position, the astronomer sets the plateholder on an elevating bracket in the box and closes the doors. When a switch is set to the "up" position, a motor-driven cable slowly lifts the plateholder upward along the vertical blade of the cross-shaped supporting "spider" until it locks into position at the intersection of the spider blades. The metal cover over the plateholder that protected the sensitive plate from light while it was carried from the loading room to the telescope is automatically removed when the plateholder is raised from the loading box. The photographic plate is protected from unwanted light while in the telescope by the clam-shell shutters at the upper end of the tube. (The bright circle at the right-hand end of the tube beyond the clam-shell shutter is the 48-inch diameter corrector plate.) Only when the telescope has been aimed and the astronomer is ready to start the exposure is the shutter opened. At completion of the exposure the shutter is closed, the telescope is moved back to the loading position, and the switch is set to the "down" position, putting the entire process into reverse operation. The plateholder is lifted from the box and another inserted, ready for the next exposure.

Filters can be mounted in front of the plateholder if it is desired to study objects in light of different colors.

The 14-inch square plates are only used when large areas of the sky are recorded. Plates 10 inches square can be used for smaller areas, and for pictures of single galaxies or small nebulae, plates only 5x7 inches can be used.



The Lunar Crater Clavius

This large crater, located in the rough southern portion of the moon, is one of the major features in that region. The small crater in the lower left-hand wall of Clavius is named "Porter" for the very man who made the drawings shown in these pages.

This crater, Clavius, seen with a string of smaller craters forming an arc across its level floor, is so large that the whole of Switzerland could be placed inside its towering walls. The encircling rim rises 17,000 feet above the floor.

This picture conspicuously illustrates the reason why large telescopes are not well suited to the photography of such objects as the moon and planets where minute detail exists. Study of this picture reveals a disturbing element caused by its lack of sharpness. This is not due to any deficiency of the 200-inch telescope with which the picture was taken, or to faulty technique in preparing the reproduction; it is due to the inhomogeneity of the earth's atmosphere through which the light rays passed.

As everyone is aware, the stars twinkle. On some nights and in some geographic locations they twinkle more than others. This rapid fluctuation of the starlight is caused by turbulence (churning) in the atmosphere resulting from thermal gradients, or heat waves. Light rays are deviated from perfectly straight paths by such disturbances, giving their source the appearance of slight random motion, just as objects across a hot stove or pavement appear to tremble and jitter.

Observatories are purposely located on mountain tops to get above the worst of these atmospheric disturbances, and, although the conditions at Palomar are particularly stable, the best photographs of the moon and planets have been obtained with small telescopes on board spacecraft that have been sent to the neighborhoods of these objects. The large ground-based telescopes, such as the 200-inch, are much more effectively used for studies of the stars, gaseous nebulae, and galaxies shown in the following pages.



The North America Nebula in Cygnus; NGC* 7000

This nebula derives its name from its striking resemblance to the outline of the continent of North America. It was photographed in red light with the 48-inch Schmidt telescope.

Space is often referred to as a perfect vacuum, but this is not quite true. While it is a far better vacuum than is currently available on earth, there are an average of 3 atoms per cubic centimeter (approximately 50 per cubic inch) in outer space. Due to special conditions in local areas this number can be much higher, resulting in the presence of discrete clouds of gas or dust. If located near bright stars, such clouds can reflect starlight and become visible. An unilluminated dust cloud can blot out all light from objects on the far side—as viewed from the earth—and it is then seen in silhouette. Gas clouds illuminated by very hot stars that produce powerful ultraviolet radiation are often made luminous by a process known as fluorescence, wherein atoms of gas absorb ultraviolet energy and reradiate it in visible colors that are characteristic of the type of gas involved. Such clouds form the bright nebulae. Often bright and dark nebulae are found in close association, as is the case in the picture at the left.

The North America Nebula, so-called because of its resemblance to the outline of the continent of North America, is composed of two such clouds. The more distant is luminous gas that acts like a giant fluorescent screen. Between the earth and this glowing cloud is another, composed of opaque dust. Depending upon its density or its thickness in local areas, this cloud absorbs more or less of the light from the bright cloud beyond it, creating a delicate tracery of detail that is amazingly intricate. As is true of the absorbing material, the density or thickness of the luminous cloud affects its brightness in local areas, creating delicate patterns.

In the lower right-hand portion of the picture it will be noted that stars are much less numerous than in the rest of the picture. Those stars lie between the earth and the opaque cloud, which not only blocks out the light of the nebula beyond, but the more distant stars as well.

Photographs of bright stars taken with most large telescopes display a four-pointed pattern; the very brightest also display a halo. These features are not part of the stars, but are optical effects created within the telescope. The four-pointed star is caused by the supports that hold the optical parts of the telescope and the plateholder in alignment; the halos are the result of light from intensely bright star images passing through the photographic emulsion and reflecting back to the emulsion from the glass surface of the photographic plate.

*NGC stands for New General Catalogue, a comprehensive catalogue of nebulae and galaxies.



A Large Planetary Nebula; NGC 7293

*This interesting body of gas shines
as a result of powerful ultraviolet
radiation from the central hot star,
which causes the gas to fluoresce.
Photographed through a red filter
with the 200-inch telescope.*

In addition to hundreds of gaseous nebulae in our Galaxy that have irregular shapes, such as the North America Nebula shown on the preceding page, there are other hundreds with much more symmetrical outlines. Some resemble rings, like the one shown at the left, while others appear as solid circular disks. In early days, when telescopes were small, these looked so much like distant planets that they came to be known as "planetary nebulae." All of them have one thing in common—an extremely hot central star that radiates powerfully in the ultraviolet portion of the spectrum.

The nebula was formed when the host star erupted many thousands of years ago and threw off a cloud of gas more or less uniformly in all directions. The nebula has now expanded to form a hollow spherical shell. All such nebulae depend upon their central star for the energy to maintain their luminosity. If this star were to be extinguished, the planetary nebula would cease to shine, and we would be completely unaware of its existence.

The gases surrounding a very hot star shine by a process very similar to that by which many minerals and certain other substances gleam in the dark when placed under an ultraviolet (black light) lamp. The process is known as fluorescence. Ultraviolet light is absorbed by certain atoms with the result that one or more of their electrons are boosted into orbits different from those they normally occupy. After a brief interval in this charged or "excited" state, the electrons drop back into their old orbits around the atom's nucleus, releasing the absorbed energy as radiation of specific wavelengths or colors that are characteristic of the type of atom involved.

The nebula shown at the left is unique among such objects because of the faint radial streaks around the inside of the ring, all pointing directly at the central star like the spokes of a wheel. It is not definitely known what causes these radial features.



The Crab Nebula; NGC 1952, Messier 1

The Crab Nebula is shown here as photographed in red light with the 200-inch telescope. This nebula may be the remains of the Supernova of 1054 A.D., which was recorded by Chinese and Japanese astronomers.

About the year 5500 B.C., a star suddenly exploded with tremendous flare of light. In a matter of hours it became several million times brighter than it had been previously. The sudden burst of light, traveling at the rate of 186,000 miles per second, finally reached the earth on the morning of July 4, 1054 A.D. Chinese and Japanese astronomers saw this "new" star in the eastern sky shortly before dawn and recorded it in their archives. At its peak the nova was bright enough to be seen in broad daylight with the unaided eye, and at night it cast shadows. Recent discovery of unusual drawings in association with prehistoric ruins in Arizona suggests that early inhabitants of the Southwest also observed and recorded the spectacle.

Hundreds of years later, when sufficiently powerful telescopes became available, a diffuse nebula was found close to the position in which the Oriental astronomers reported the exploding star, a nebula unlike any other yet found in our Galaxy. It literally looks like the shedded remains of a gigantic explosion with its twisted streamers of gas extending in all directions.

These streamers, faintly seen through early telescopes, gave astronomers the impression of numerous legs writhing around the central nebulosity and led them to name the object the "Crab Nebula."

Most luminous nebulae shine because of the light emitted by nearby stars. The Crab Nebula is different. A large fraction of its light is due to radiation from very high-energy electrons moving in a magnetic field. This radiation is emitted across the entire electromagnetic spectrum from x-rays to radio wavelengths.

The source of these energetic electrons is a pulsar, a rapidly rotating neutron star as massive as the sun but only a few miles in diameter. Its period of rotation is about 1/30 of a second. The pulsar is the remnant of the 1054 A.D. supernova.

The violence of the supernova explosion is indicated by the rate at which the cloud of gas is still expanding; the diameter of the nebula is increasing at the rate of *approximately 70 million miles per day!* If one assumes that this rate of expansion has been constant since the original event, and one knows the present diameter of the nebula in miles, it is possible to compute the length of time that has elapsed since the expansion began. The result agrees satisfactorily with the time recorded in the ancient Oriental archives.



The Star Cluster in Hercules; NGC 6205, Messier 13

Stars sometimes cluster into symmetrical swarms like the one shown at the left. There are over one hundred such clusters in our Galaxy. Photographed with the 200-inch telescope.

Within our Galaxy are many groups of stars called clusters. About 120 of these are highly concentrated, symmetrical groups called globular clusters, like the one shown in the photograph at the left. These clusters are widely scattered in a halo around the nucleus of the Galaxy, at distances ranging from 21,000 to 100,000 light years. Although only about 120 of these clusters have been catalogued, there undoubtedly are many more hidden by the dense star clouds that make up our Milky Way.

It has been estimated that the number of stars in each of these clusters ranges from 100,000 to 10,000,000 depending upon the size of the cluster. The diameter of such clusters may be as large as 100 light years (100 times 6 trillion miles).

The stars in globular clusters are probably the oldest stars in our Galaxy—their age is estimated to be about 15 billion years. For comparison, our sun, which is a star, is only about 5 billion years old.

The globular cluster shown at the left is one of the best known because it is a favorite object for amateur astronomers, and can even be seen on a dark night as a starlike object in the constellation of Hercules. Small telescopes reveal it as a diffuse object with only the brightest stars resolved into individual points of light. It requires photographs to disclose the vast number of tightly packed stars that compose the cluster.

Most of the stars in this cluster are much brighter than our sun, which would be barely detectable, even with the 200-inch telescope, if it were a member of the cluster. It is often disappointing for people to learn that our sun is a very insignificant star in our Galaxy.



The Great Galaxy in Andromeda; NGC 224, Messier 31

Far out in space, beyond the constellation of Andromeda in our own Galaxy, lies our nearest neighboring spiral galaxy, shown at the right in a picture taken with the 48-inch Schmidt telescope. It is a spiral galaxy closely resembling our own Milky Way system.

As we look outward from the earth at the night sky, we see stars everywhere we look. If we look closely, we soon realize that there are more stars in some areas of the sky than in others. If it is summertime, we soon notice that in the south there is a band of hazy light extending upward from the horizon into the northern sky. This is the Milky Way, composed of vast clouds of stars so numerous that the majority cannot be resolved by the unaided eye. The reason for this concentration of stars in a broad band across the sky is this: our sun and its family of planets lie in the outer one-third of a lens-shaped swarm of stars. When we look into space in a direction perpendicular to the plane of the swarm, we see relatively few stars, but when we look along the plane of the swarm, we see a tremendous number of stars, because we are looking outward along the plane of the Milky Way, the brightest region in the southern summer sky in the direction of the nucleus of our Galaxy.

Our Galaxy is shaped very much like the one shown at the left which lies far beyond the most distant stars in our system. Its distance is 2,300,000 light years, a light year being equivalent to 6 trillion miles, the distance light travels in one year while moving at the speed of 186,000 miles per second. This is one of the nearest of the thousands of spiral galaxies scattered through the vast stretches of space. It is composed of the same type of stars, star clusters, and nebulae as are found in our Galaxy.

The two elliptical objects close to the Andromeda Galaxy are small satellite galaxies lying a short distance beyond the outskirts of the large spiral. They are of a different type and display no spiral arms. Although the large galaxy appears elliptical in shape, this is only the result of foreshortening due to its orientation in space.

The individual stars scattered rather uniformly over the entire photograph are within our own Galaxy and are only a few thousand light years from us. Between the most distant of these stars and the Andromeda Galaxy lie billions of miles of space, empty except for widely scattered atoms of gas and minute particles of dust. Such dust occurs in vast clouds in some types of galaxies, such as ours and the Andromeda Galaxy, and can be seen in the picture at the left as the dark lanes between the clouds of stars making up the spiral arms. Examples of such clouds of dust in our Galaxy can be seen in the picture on page 50.



The Spiral Galaxy; NGC 598, Messier 33

This is another nearby galaxy where individual stars, gaseous nebulae, and internal dust are clearly visible.

Galaxies are of various shapes and sizes. Many are quite symmetrical with spiral patterns coming from the central regions. The Andromeda Galaxy shown on the previous page, and the one in the constellation of Triangulum shown at the left, is quite normal. The galaxy shown at the left is seen nearly face on (that is, perpendicular to the plane of its disk), unlike the Andromeda Galaxy shown on page 58, which appears elliptical because it is seen from an angle. It is slightly too large to be photographed in its entirety by the 200-inch telescope, with the result that the ends of the spiral arms are not shown, and star images at the corners of the picture are distorted because of optical aberrations.

The number of stars in galaxies ranges from several hundred thousands to tens of billions. The diameters and intrinsic brightnesses of the stars likewise cover a very wide range. Some of the brightest stars in galaxies are concentrated along the spiral arms while the fainter, and usually cooler, stars are concentrated more around the nucleus.

Galaxies rotate about their centers very slowly. It is estimated that our sun, with its system of planets, makes one trip around the center of our Galaxy in about 250,000,000 years. If it were located at the outside edge of the Galaxy, it would take even longer for a complete circuit.

Clearly visible in the picture are clouds of opaque dust that obliterate the light from background stars in certain areas, creating dark lanes between the arms of the galaxy. In the pictures in preceding pages, we have seen examples of such dark clouds of dust in our own Galaxy, where such dust overlays bright nebulae.

The galaxy M33 at the left, like the galaxy in Andromeda, is a near neighbor of our own Galaxy, and lies at a distance of only about 2,000,000 light years. This means that the light that made this picture was rushing through space at a speed of 186,000 miles per second toward the earth for 2,000,000 years before it was captured by the telescope and photographic plate.



The Horsehead Nebula in Orion; NGC 2024

This gaseous nebula, located in our Galaxy, is called the "Horsehead" for obvious reasons. It is located near the star Zeta Orionis, the left-hand star in the belt of Orion, a very well-known constellation in the winter sky. Photographed through a red filter with the 200-inch telescope.

This is an unusually interesting example of light and dark nebosity. Vast clouds of gas and dust are being illuminated by ultraviolet light from a nearby hot star. The gas shines by fluorescence, as described in connection with the nebula on page 53. Stretching across the center of the picture is a long billowing wall of opaque material whose surface is illuminated while one large protuberance, by pure chance, resembles the head of a horse in silhouette.

An interesting curtain of bright streamers extending perpendicular to the long wall of nebosity behind the horse's head is not clearly understood. It resembles thin jets of material escaping from the dense cloud, but no explanation for such "streaming" of material from one area into another has been proposed.

The difference in the number of stars below the horse's head compared to those above is a conspicuous demonstration that the cloud of opaque material is obstructing all light from the more distant stars. Those few seen against the dark cloud are on this side of the opaque material.

The sky is full of beautiful bright and dark nebulae, some exhibiting fantastic shapes. But this Horsehead Nebula is one of the most popular astronomical objects.

Its distance is about 3000 light years.

Back Cover:

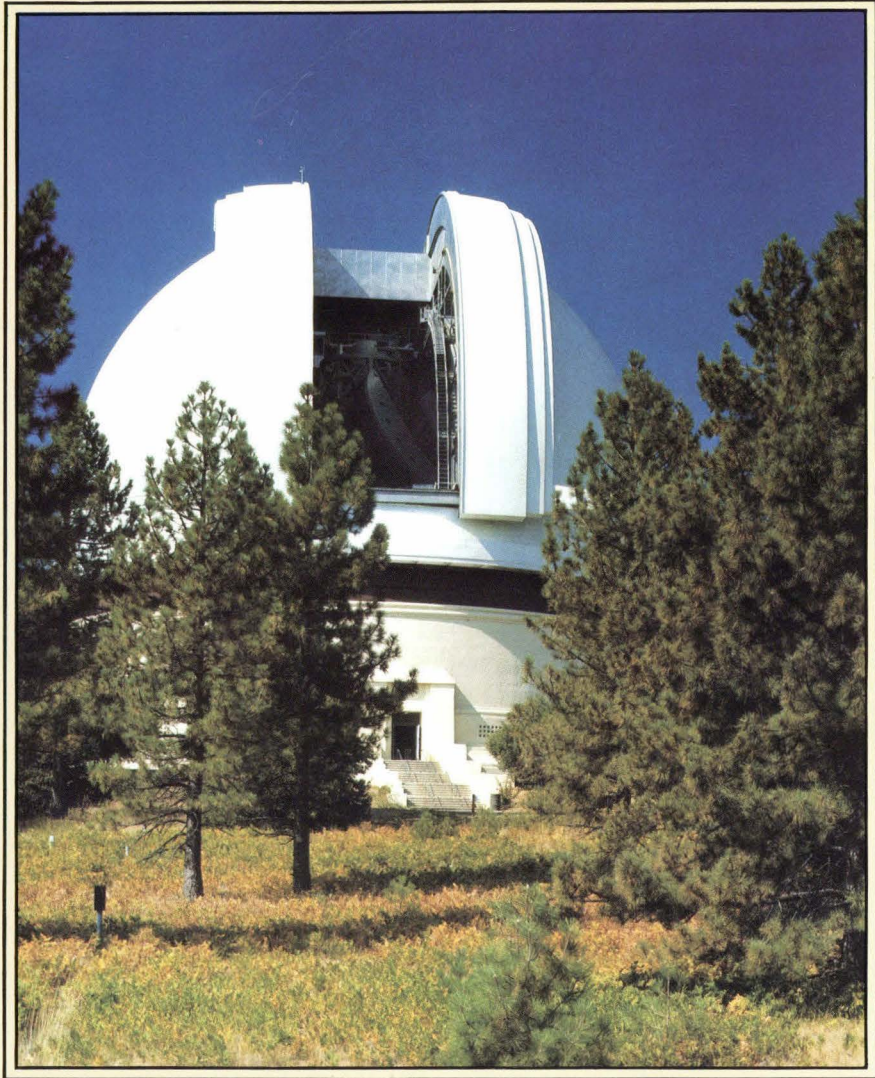
Palomar Observatory

Located atop a 5600-foot-high mountain ridge, the instruments are above most atmospheric disturbances that adversely affect the performance of telescopes. The site was carefully chosen because of its clear, stable atmosphere and, at that time, dark sky. Urban development, with its pollution and street lights, has become a serious threat to astronomical research at Palomar.

Dominating the landscape on a broad, relatively flat area on Palomar Mountain is the dome of the 200-inch Hale Telescope. The shutters of the dome were opened only briefly for the benefit of the picture; they are normally kept tightly closed during daylight hours to protect the instrument within from changes in temperature between day and night.

Elsewhere on the site are the 60-inch telescope (operated jointly with the Mount Wilson and Las Campanas Observatories), the 48-inch Schmidt, the 18-inch Schmidt, the lodge where astronomers stay during their assigned time at Palomar, shops, offices, and the residence for the maintenance personnel and their families.

The observatory was located on Palomar Mountain only after several years of painstaking tests of more than a score of sites ranging from Catalina Island on the west to Flagstaff, Arizona, on the east, and from Mono Lake on the north to the Mexican border on the south. After careful study of the test data Palomar was selected for having the greatest number of points in its favor. Such items had to be considered as access roads, adequate local water supply, accessibility from Caltech in Pasadena, sufficient level ground for buildings and domes, good elevation, freedom from clouds on the majority of nights, stable atmospheric conditions, and dark skies. As new communities appear and expand near Palomar, the glare of street lighting has adversely affected work at the observatory. Efforts are being made to enlist the help of local governments in the task of limiting further light pollution; otherwise Palomar's future as a major center for astrophysical research will be in jeopardy.



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